National Aeronautics and Space Administration

The Earth Observer. November - December 2014. Volume 26, Issue 6.

the earth observer

# Editor's Corner

***Steve Platnick***
*EOS Senior Project Scientist*

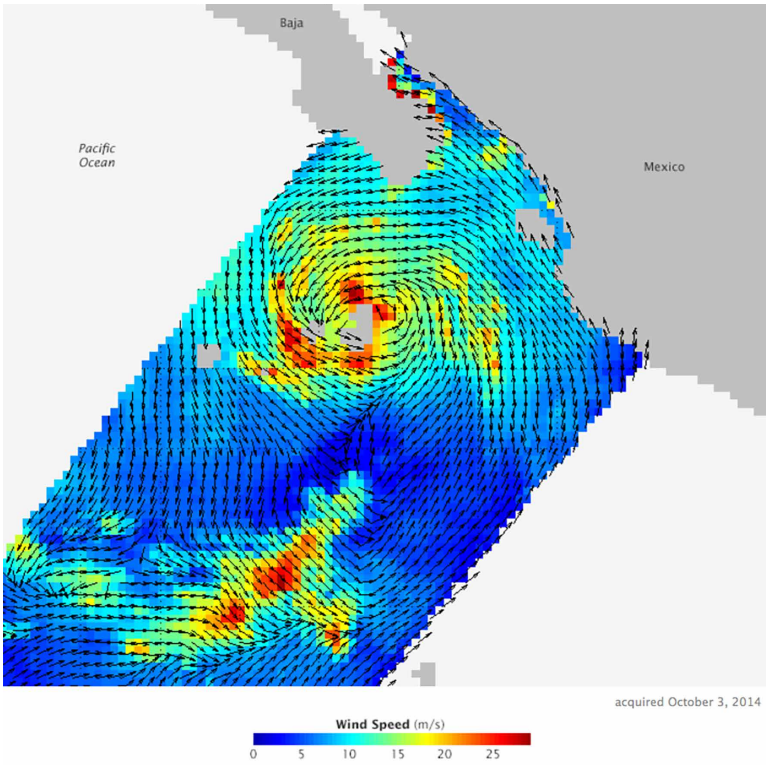
Remarkably, another year is drawing to a close. And a remarkable year it was for NASA Earth Sciences. It is inevitable at this time of year that we reflect on the milestones of the year that was and look ahead to the year that will be.

One such milestone was the tenth anniversary of the Aura mission. In a previous Editorial, we highlighted some of the celebratory events held on July 14—the actual anniversary date—at NASA's Goddard Space Flight Center (GSFC) to commemorate the occasion[1]. Aura was the third of the three flagship missions for the Earth Observing System (the others being Terra and Aqua), and was designed to study the processes at work in Earth's atmosphere. Its measurements have made significant contributions in understanding the ozone layer, air quality, and climate. The stand-alone feature in this issue is an article, written by Former Aura Program Scientist **Ernest Hilsenrath**, called *Celebrating Ten Years of Aura Observations*—see page 4. The article contains a summary of Aura's scientific discoveries, arranged around its three science themes.

Throughout 2014, we have been reporting on NASA's ambitious plan to launch five[2] Earth science missions within the span of a year, which began in February with the GPM Core Observatory. Now with the successful launches of GPM, OCO-2, and ISS-RapidScat behind us, we turn our attention to the CATS payload, which is scheduled for launch on December 16, 2014.

[1] See the Editorial of the July–August 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 4**, pp. 2-3].
[2] The five missions are GPM, OCO-2, ISS-RapidScat, CATS, and SMAP.

continued on page 2




Barely two weeks after its launch and two days after its installation, the ISS-RapidScat captured this view of the wind field around Tropical Storm Simon (which later developed into a hurricane). The map shows preliminary, un-calibrated measurements of wind speed and direction at 7:10 PM local time on October 3, 2014 (0210 Universal Time on October 4). Arrows show the direction of winds at the ocean surface, colors show the estimated speed. The solid gray area represents the land. "Most satellite missions require weeks or even months to produce data of the quality that we seem to be getting from the first few days of RapidScat," said **Ernesto Rodriguez** [NASA Jet Propulsion Laboratory—*Project Scientist*]. **Credit:** NASA's Earth Observatory

editor's corner

## In This Issue



**Reminder:** To view newsletter images in color, visit *eospso.nasa.gov/earth-observer-archive.*

CATS was shipped to SpaceX at Canaveral Air Force Station in Florida on September 30, where it was successfully integrated on the SpaceX-5 Dragon capsule that will carry it to the International Space Station. In anticipation of launch, the team is continuing to test and refine Level 0 and Level 1 data processing algorithms. CATS will provide vertical profiles of cloud and aerosol properties at three wavelengths (1064, 532, and 355 nanometers) from its mounting location on the Japanese Experiment Module – Exposed Facility (JEM-EF)—the first NASA-developed payload to ever fly on the JEM-EF. The mission seeks to build on the CALIPSO data record, provide observational lidar data to improve research and operational modeling programs, and demonstrate new lidar retrievals of clouds and aerosols from space. On page 17 of this issue, we announce the release of the CATS mission brochure, which is now available online.

Meanwhile, SMAP is also preparing for launch—which is now set for January 29, 2015, from Vandenberg Air Force Base (VAFB) in California. SMAP passed its Pre-Ship Review on October 15 and then was shipped to VAFB. The mission subsequently passed its Operational Readiness Review (November 4-5) and Mission Readiness Review (November 7). The Delta-II launch vehicle that will carry SMAP into orbit is already stacked at a launch pad at VAFB.

The GPM Core Observatory, launched February 27, continues to perform nominally as of this writing. In this issue we report on the Precipitation Measurement Missions (PMM) Science Team Meeting, which took place August 4-7 in Baltimore, MD. The highlight of that meeting was a symposium held in honor of the former GPM Project Scientist, **Arthur Hou**, who passed away November 20, 2013. Among those who spoke were **Michael Freilich** [NASA Headquarters (HQ)—*Director of the Earth Science Division*], **Ramesh Kakar** [NASA HQ—*GPM Program Manager*], **Piers Sellers** [GSFC—*Deputy Director of Science and Exploration Directorate*], other colleagues, and friends from throughout Hou's long and distinguished career, as well as Hou's wife Sandra and daughter Sara. Hou was remembered as an exceptional scientist and leader who was able to build and navigate the international relationships that got the GPM mission off the ground. Turn to page 29 of this issue to read more about the meeting; the memorial symposium is summarized on page 32.

OCO-2 launched on July 2 and entered nominal operations in early October. It has been returning almost one million soundings each day over Earth's sunlit hemisphere. As expected, between 10 and 20% of these soundings are sufficiently cloud free to yield accurate estimates of the column averaged carbon dioxide ($CO_2$) dry air mole fraction, $X_{CO2}$. Preliminary analysis of the

early measurements are promising, though some aspects of the calibration still need refinement to meet the mission's stringent accuracy requirements. The OCO-2 team is on track to start routine deliveries of Level 1B products (i.e., calibrated spectral radiances) to the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) before the end of the calendar year. The first routine deliveries of Level 2 products, including $X_{CO2}$, surface pressure, and chlorophyll fluorescence, are planned for late March 2015.

Our last issue reported in detail on ISS-RapidScat[3], which launched on September 21. Though only two months have passed since launch, scientists are already well on their way to accomplishing one of the major mission objectives. They have successfully cross-calibrated ISS-RapidScat low-resolution [25 km (15.5 mi)] ocean wind data with QuikSCAT and validated the data against ground measurements[4]. The team reports the ISS-RapidScat data are meeting all planned wind performance requirements and are ready to begin extending the long-term climate data record of ocean-surface winds begun by QuikSCAT in 1999. This schedule is two months ahead of what was anticipated. Congratulations to **Ernest Rodriguez** [JPL—*Project Scientist*] and the entire RapidScat team. The image on the front cover shows an example of data being produced from RapidScat.

In addition to the five missions mentioned above, there is another upcoming launch worth noting. The joint NOAA–U.S. Air Force–NASA Deep Space Climate Observatory (DSCOVR[5]) mission is scheduled to launch in January 2015. While the primary goal of DSCOVR is to make solar wind and magnetic field measurements to enable space weather forecasting, NASA has integrated two Earth-observing instruments that will make the first continuous Earth observations from the Sun-Earth Lagrange point (L1), which is located 1.5 million km (930,000 mi) from Earth on the line between Earth and the sun.

The two NASA Earth Science instruments on DSCOVR are the Earth Polychromatic Imaging Camera (EPIC) and the NIST Advanced Radiometer (NISTAR). EPIC images radiances from the sunlit face of the Earth on a 2048 x 2048 pixel CCD in 10 narrowband channels (from ultraviolet to near infrared) with a nadir pixel size of approximately 8 km. The unique L1 vantage point will allow EPIC to provide sunrise to sunset imagery of our planet. The primary science products expected from EPIC are global ozone levels, sulfur dioxide and ash, aerosol index and aerosol optical depth, cloud height over land and ocean, spectral surface reflectance, vegetation, and leaf area indices. NISTAR measures the absolute irradiance integrated over the entire sunlit face of the Earth in four broadband channels, allowing for daytime global Earth radiation budget studies.

The NASA Science Mission Directorate recently selected nine proposals for the development of EPIC and NISTAR algorithms in support of the Earth Science Division. The first DSCOVR Earth Science Algorithm Meeting was held at NASA GSFC on November 14, 2014. In addition to proposed science algorithms, the team also discussed EPIC and NISTAR calibration as well as the responsibilities and requirements of the DSCOVR Science Operation Center (DSOC) at GSFC and Atmospheric Science Data Center (ASDC) at Langley Research Center.

With three launches complete, three more scheduled by the end of January, and numerous sub-orbital and/or ground-based campaigns—NASA's Earth Science Division has had a very busy 2014. We recognize the

continued on page 36

**Acronyms used in the Editorial and Article Titles**

| | |
|---|---|
| CATS | Cloud–Aerosol Transport System |
| CCD | Charge Coupled Device |
| GSFC | NASA's Goddard Space Flight Center |
| GPM | Global Precipitation Measurement |
| HIRDLS | High Resolution Dynamics Limb Sounder |
| ISS-RapidScat | International Space Station Rapid Scatterometer |
| JPL | NASA/Jet Propulsion Laboratory |
| NIST | National Institute of Standards and Technology |
| OCO-2 | Orbiting Carbon Observatory-2 |
| QuikSCAT | Quick Scatterometer |
| SMAP | Soil Moisture Active Passive |

[3] See both the Editorial and "ISS-RapidScat: Measuring Ocean Winds from the International Space Station" in the September–October 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 5**, pp. 4-10].

[4] Calibration of the higher resolution (12.5 km) data is ongoing. A longer period of overlap between RapidScat and QuikSCAT is required to obtain the level of precision needed to extend the climate data record.

[5] DSCOVR was originally designed as a NASA Earth observing mission known as Triana—with plans to launch on the ill-fated flight of Space Shuttle Columbia, STS 107. For a variety of reasons, those plans were scrubbed, and the spacecraft set in storage until 2008, when it was refitted for launch on a Falcon 9. The mission has since been renamed, and reworked so that its primary purpose is to make solar observations, and replace the aging Advanced Composition Explorer (ACE) spacecraft.

feature articles

# Aura Celebrates Ten Years in Orbit

*Ernest Hilsenrath[1], NASA Retired, Fellow at the Joint Center for Earth Systems Technology, Global Science and Technology, Inc., hilsenrath@umbc.edu*

*Just over ten years ago, the NASA launch and science teams assembled at Vandenberg Air Force Base in California in preparation for the Aura launch. After two delays due to minor problems, on July 15, 2004, shortly after 3:00 AM PDT the Delta II rocket lifted off, carrying the spacecraft toward a polar, sun-synchronous orbit at about 705 km (~438 mi).*

## Introduction

Just over ten years ago, the NASA launch and science teams assembled at Vandenberg Air Force Base in California in preparation for the Aura launch. After two delays due to minor problems, on July 15, 2004, shortly after 3:00 AM PDT the Delta II rocket lifted off, carrying the spacecraft toward a polar, sun-synchronous orbit at about 705 km (~438 mi). After the satellite reached altitude, it executed a series of four inclination maneuvers, the first taking place on September 9. By October 1 Aura was in position trailing 15 minutes behind NASA's Aqua spacecraft, with an equator-crossing time of 1:30 PM local time—and the Afternoon Constellation, or A-Train, was born. Still in orbit today, Aura has well exceeded its five-year mission lifetime.

Originally known as EOS-CHEM, Aura was the third "flagship" mission of NASA's Earth Observing System (EOS), the other two being Terra (launched in 1999) and Aqua (2002), which were both already collecting data on land, water, clouds, ice, and aerosols. In addition to the other two flagship missions, there were five other EOS missions in orbit in 2004: the Tropical Rainfall Measuring Mission (TRMM); Gravity Recovery and Climate Experiment (GRACE); Solar Radiation and Climate Experiment (SORCE); Quick Scatterometer (QuikSCAT); and Ice, Cloud, and land Elevation Satellite (ICESat). Extending the overall complementarity of these missions, Aura measurements focus on atmospheric chemistry and dynamics and interactions with climate, from the mesosphere to the troposphere, and their evolution over time. The mission has a unique capability to explore the lower stratosphere and troposphere to near Earth's surface, where humans affect atmospheric composition, including air quality.

This article provides an overview of Aura results over the 10 years since its launch, and acknowledges the work of more than 200 researchers. Their work has been reported during many Aura science and instrument team meetings, and has so far resulted in about 1400 peer-reviewed papers. The author also acknowledges the Project Science Team at NASA's Goddard Space Flight Center (GSFC) and program scientists at NASA Headquarters. Aura celebrated its Tenth Anniversary Science Team Meeting in College Park, MD, September 15-18, 2014, with about 200 people attending. The Aura program scientist and project scientists (present, former, and retired) appear with instrument principal investigators (PIs) and their deputies in the photograph below.


Current and former project scientists and principal investigator (PI) teams and the NASA HQ program manager assembled at Aura's tenth anniversary science team meeting. [*Left to right*]: **Jessica Nue** [Deputy TES PI], **Michel Santee** [JPL Atmospheric Science Group Leader], **Bryan Duncan** [Deputy Project Scientist], **Pepijn Veefkin** [OMI Co-PI], **Nathaniel Livesey** [MLS PI], **Ken Jucks** [Program Manager], **Lucien Froidevaux** [MLS Deputy PI], **John Gille** [HIRDLS PI], **Pieternel Levelt** [OMI PI, Netherlands], **Ernest Hilsenrath** [Former OMI Co-PI, U.S., Former Deputy Project Scientist, and Former Program Manager], **Johanna Tamminen** [OMI PI, Finland], **Anne Douglas** [Project Scientist], **Joanna Joiner** [Deputy Project Scientist], and **Pawan Bhartia** [OMI Co-PI, U.S.] **Photo credit**: NASA

[1] Hilsenrath served as GSFC OMI Co-PI and Aura Deputy Project Scientist (1999-2005), Headquarters Aura Program Scientist (2006-2010).

**Aura's Mission**

One of Aura's highest priorities was to continue the measurements of the Upper Atmospheric Research Satellite (UARS), which at the time of launch, was in its thirteenth year of operation and beginning to fail. In addition, Aura would explore Earth's atmosphere as was never done before. Three instruments were initially chosen to fly on the mission: the High Resolution Dynamic Limb Sounder (HIRDLS), the Microwave Limb Sounder (MLS), and the Tropospheric Emission Spectrometer (TES). The Netherlands and Finland contributed the fourth instrument, called the Ozone Monitoring Instrument (OMI), which was added to the payload later[2]. OMI became an ideal complement to the other three instruments, as well as a worthy successor to the long line of heritage Total Ozone Measuring Spectrometer (TOMS) instruments. Each of these instruments was built on a solid pedigree of success because their technology was tested either on earlier satellites, aircraft, or balloons. Expectations for quality data were high all four instruments, and ultimately met and exceeded their performance requirements, as will be noted below. Links to information about each instrument can be found at *aura.gsfc.nasa.gov*.

The Aura instruments observe the atmosphere looking horizontally through the atmosphere (the *limb)* and looking down through the atmosphere (the *nadir*). In addition, the instruments cover a wide spectral range, from ultraviolet (UV) to microwave wavelengths. The only other spacecraft to come close to this compliment of capabilities was the European Space Agency's Envisat[3], which is no longer operating.

## Aura Mission Success Criteria

In coordination with the Aura project scientist and program scientists at NASA Headquarters, the team developed the following Mission Success Criteria, which address the mission's overall science questions and serve as the basis for each instrument's performance requirements.

- ***Quantify the change in stratospheric ozone in response to decreases in chlorofluorocarbons and increases in greenhouse gases, as well as extending the high precision measurements of global column ozone for use in trend detection.***
- ***Determine the linkage between climate change and changes in atmospheric constituents.***
- ***Determine how localized tropospheric pollution sources contribute to regional and global pollution.***
- ***Determine natural and anthropogenic influences on the global oxidizing power of the troposphere.***

The instrument capabilities are highly synergistic and were designed to fulfill the three major goals of the mission and the mission success criteria—see *Aura Mission Success Criteria*. The mission goals are to:

1) Explore and detect changes in the stratospheric ozone layer as ozone-depleting substances decrease and the stratosphere cools due to greenhouse gas increase.

2) Study the processes that control tropospheric air quality, particularly due to continental-scale changes in pollutant emissions that result from industrialization, economic growth, and regulations (or lack thereof).

3) Discover the connections between atmospheric composition and chemistry and climate, focusing on water vapor, ozone, and aerosols in the upper troposphere and lowermost stratosphere.

*Aura Instruments and Data Products*

Those who proposed the selected instruments became the initial Aura mission science team, with responsibility for building and calibrating the instrument, developing algorithms, and processing and validating the data. Two of Aura's instruments

[2] To learn more about "How OMI Became part of Aura" refer to the May–June 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 3**, p. 24].
[3] To learn more about Envisat, please see "An Overview of Europe's Expanding Earth-Observation Capabilities" in the July–August 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 4**, pp. 4-15].

*Aura is truly an observatory. Many of the papers at the Tenth Anniversary Science Meeting used data from more than one Aura instrument and in a few instances three of four instruments. As we hoped and planned for, Aura is more than the sum of its instruments.*

**—Jim Gleason** [NASA's Goddard Space Flight Center—*Suomi NPP Project Scientist and Former Aura Project Scientist*]

have international contributions: OMI from the Royal Netherlands Meteorological Institute [Koninklijk Nederlands Meteorologisch Instituut (KNMI)] and Finnish Meteorological Institute (FMI), and HIRDLS from Oxford University. **Table 1** includes the original and current instrument principal investigators (PIs) and data products for each instrument. The data products follow from the Mission Success Criteria—see sidebar on page 5.

*Instrument Data Product Synergies*

Each of Aura's instruments contributes to all three of the mission science themes: ozone chemistry and trends, pollution's impacts on air quality, and climate forcing. For stratospheric ozone science, OMI measures total column and vertical amounts of ozone, while HIRDLS and MLS measure ozone profiles with high vertical resolution, which together quantify how ozone is changing over time. HIRDLS and MLS further complement each other with their measurements of chlorofluorocarbons (CFCs[4]) and their by-product—the decrease in measured ozone. OMI, with its high accuracy and mapping capability, tracks the size and "depth" of the annual Antarctic ozone hole.

Measurements from TES and OMI are used to study air quality; these two instruments detect and map five of the six Environmental Protection Agency (EPA) *Criteria Pollutants*: ozone ($O_3$) in the lower troposphere, sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), carbon monoxide (CO), and particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$). TES and OMI can measure tropospheric ozone directly, but OMI can also derive tropospheric ozone amounts by using stratospheric ozone profiles from MLS to subtract from its column amounts. Tropospheric ozone column amounts have been shown to be a fairly good indicator of boundary layer ozone during some high-pollution events.

[4] CFC-11 and CFC-12 were formerly used as refrigerants, but were banned under the 1987 Montreal Protocol. These gases are chemically inert in the lower atmosphere, but they are long-lived in the atmosphere, meaning they eventually reach the stratosphere. There, they become activated in the presence of ultraviolet radiation, and begin the catalytic destruction of stratospheric ozone.

**Table 1.** Original and current instrument PIs and data products for each Aura instrument.

| Instrument | Original Instrument PI | Current Instrument PI | Measurement |
|---|---|---|---|
| High Resolution Dynamics Limb Sounder (HIRDLS) | **John Gille** [National Center for Atmospheric Research (NCAR) and University of Colorado]<br>**John Barnett** [Oxford University, U.K.] | **John Gille** [Oxford University]<br>**Lesley Gray** [Oxford University] | Temperature and composition of the upper troposphere, stratosphere, and mesosphere; aerosol extinction and cloud height |
| Microwave Limb Sounder (MLS) | **Joe Waters** [NASA/Jet Propulsion Laboratory (JPL)] | **Nathaniel Livesey** [JPL] | Temperature and composition of the upper troposphere and stratosphere; upper tropospheric cloud ice |
| Ozone Monitoring Instrument (OMI) | **Pieternel Levelt** [KNMI, Netherlands]<br>**Gilbert Leppelmeier** [FMI]<br>**Ernest Hilsenrath** [GSFC] | **Pieternel Levelt** [FMI]<br>**Johanna Timonen** [FMI]<br>**Joanna Joiner** [GSFC] | Total column ozone, tropospheric composition, aerosol absorption, and cloud centroid pressure |
| Tropospheric Emission Spectrometer (TES) | **Reinhard Beer** [JPL] | **Kevin Bowman** [JPL] | Temperature, ozone, carbon monoxide, and water vapor profiles from the surface to lower stratosphere |

Ozone becomes a greenhouse gas in the upper troposphere, and can be measured by TES and OMI. All four of Aura's instruments can measure ozone in the lower stratosphere where it is also a greenhouse gas. MLS detects cloud ice and gas composition in water clouds, which can be used to quantify the hydrological processes near the tropopause. HIRDLS's high-vertical-resolution measurements provided data on the altitude structure of winds and temperature, which enable better climate modeling and provides new data on the Earth's radiative balance. TES measurements of water vapor isotopes provide crucial clues to climate models that simulate convective processes. In addition, OMI's characterization and mapping of aerosols as they are blown around the globe also helps scientists understand climate change forcing. Uncertainty in aerosol abundance, location, and characteristics are a key source of uncertainties in climate models.

There are also synergies with the other A-train platforms, as noted in *Aura and the A-Train: Science Synergy,* on page 16.

*Aura data are being analyzed by scientists in the U.S. and throughout the world, and 10 years of observations have yielded insights into the variability and trends in stratospheric ozone, into the release of tropospheric pollutants both nationally and internationally, and into complex processes that connect gases like ozone and water vapor with climate change. Made even more powerful by synergy with other satellites in the A-train, Aura data are making it possible to quantify complex relationships among clouds, aerosols, and composition that are vital to understanding the Earth system.*

—**Anne Douglass** [NASA's Goddard Space Flight Center—*Aura Project Scientist*]

**Aura Science Highlights**

The science highlights from the first ten years of the Aura mission reported here are organized by Aura's three themes, which focus on Earth's atmosphere: *stratospheric ozone, air quality,* and *climate*. Aura's results over this period has led to about 1400 peer reviewed publications, as mentioned earlier, and two journal special issues[5]. Aura data are being used by the U.S. Global Change Research Program and for international assessments, including the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the World Meteorological Organization (WMO) and United Nations' Environmental Program (UNEP) Scientific Assessments of Ozone Depletion (SAOD), and the Task Force on Hemispheric Transport of Air Pollution (TF HTAP). Also included are noteworthy highlights from presentations at the tenth annual Aura science team meeting in September. The presentations given during the science team meeting can be found at *avdc.gsfc.nasa.gov*.

*Stratospheric Ozone*

NASA's instruments have been monitoring global ozone trends since 1978 and the data are used to test performance of chemistry–climate models (CCMs). These CCMs are used to predict the future of stratospheric ozone—for example, when the Antarctic ozone hole will close and when will global ozone amounts return to their pre-1980 levels, taking climate change into account. The TOMS instruments have been mapping the Antarctic ozone hole since it first appeared around 1979. When Aura became operational, OMI took over this mapping task from TOMS. The area of the ozone hole is determined from a map of total column ozone with values of 220 Dobson Units or lower. The hole is formed when ozone is destroyed by chemical reactions that take place within the Southern Hemisphere polar vortex, which traps and isolates very cold air over the pole.

*As originally planned, Aura didn't have an instrument operating in the ultraviolet for ozone measurements to continue the SBUV/TOMS record. The OMI instrument built by Dutch-Finnish collaboration filled an important gap in the measurements, making the Aura mission the most comprehensive atmospheric chemistry lab in space ever flown—or likely to be flown again.*

—**Pawan "P.K." Bhartia** [NASA's Goddard Space Flight Center—*Former Aura Project Scientist*]

[5] *Journal of Geophysical Research-Atmospheres*, doi:10.1029/2007JD009602/full and *IEEE Transactions on Geoscience and Remote Sensing*, doi:10.1109/TGRS.2005.861950.

Until recently, the Arctic was believed to be free of a similar phenomena. However, in 2011, for the first time, a large depletion of ozone was observed over the Arctic, occurring at the comparable season as the Antarctic ozone hole. While not as large as in the Antarctic, in April 2011 ozone-depleted air extended over large parts of central Asia, extending as far south as Mongolia—and included some densely populated areas. The cold and long-lasting Arctic polar vortex that year took everyone by surprise, but experience with the Antarctic polar processes provided the explanation for the accompanying photochemical ozone destruction.

Although the temperatures did not fall to the levels within its southern counterpart, the usually persistent Arctic polar vortex in the Arctic lower stratosphere and long-lasting cold during 2011 led to enhancement in ozone destroying forms of chlorine and to an unprecedented Northern Hemisphere ozone loss—see **Figure 1**. Because of the slow decline of CFC-11 and CFC-12—the most important of the ozone-depleting substances (ODSs)—significant ozone loss can be expected to continue to occur in the Arctic for the next several decades, during winters with meteorological conditions similar to those experienced in 2011. OMI and MLS's measurements supported the following statement in the SAOD Executive Summary: "The Antarctic ozone hole continues to occur each [Southern Hemisphere] spring, as expected for the current ozone depleting substances abundances. The Arctic stratosphere in winter/spring 2011 was particularly cold, which led to large ozone depletion as expected under these conditions."

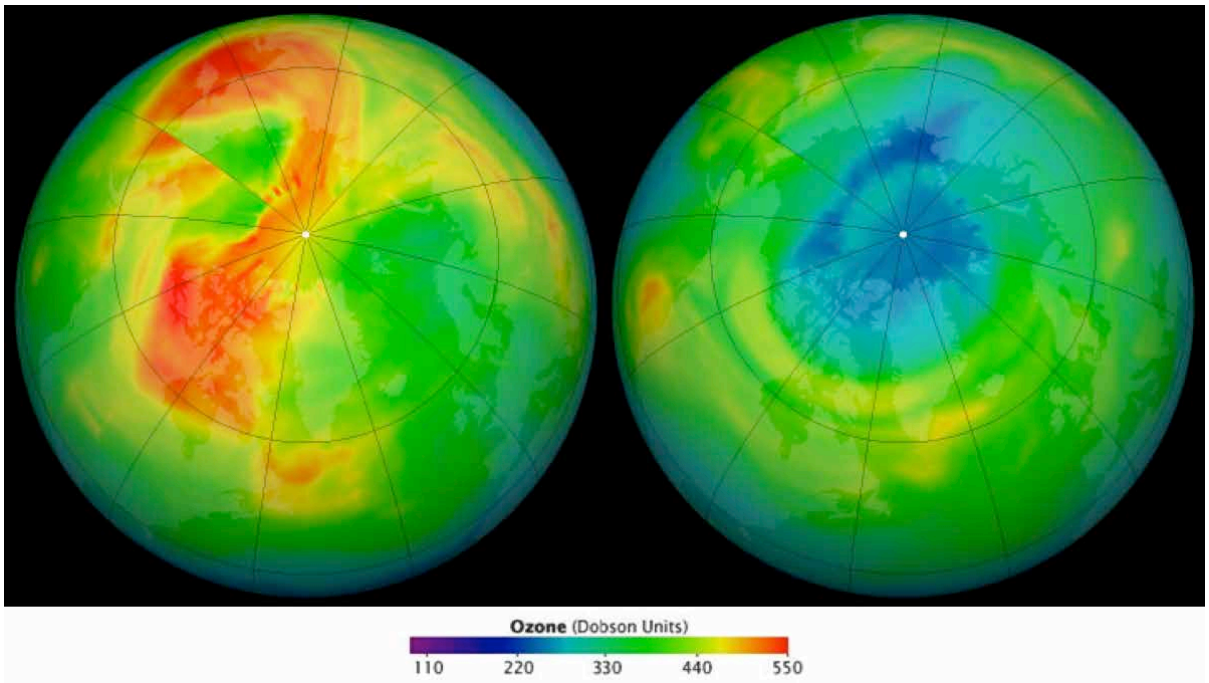



**Figure 1**. A deep Arctic ozone depletion during the 2011 late winter/spring seasons is shown on the right, compared to the more normal amounts at the same time of year for 2010, on the left. The red areas for 2010 are the normal high-ozone amounts, while the blue areas are areas of ozone depletion. Both global maps are from OMI total column ozone data. **Image credit:** NASA

An important gas species measured by MLS is hydrogen chloride (HCl), which is an indicator of how much ozone depleting chlorine remains in the stratosphere. MLS has shown that HCl concentrations, which reached maximum values in 2002 (measured by UARS), have been steadily declining. This decline is consistent with the phasing out of CFC production, and is one indicator that the 1987 Montreal Protocol, the global treaty banning ODS, is working.

*Aura has provided us a comprehensive global picture of changing air quality—pollution reduction in the developed world and deteriorating conditions in the developing world. Aura has also given us the most comprehensive picture of stratospheric processes yet achieved. As Aura's mission continues, we will continue to see changes in air quality and stratospheric ozone and we will be able to improve our models and our predictions for the future. Aura has definitely achieved more than we expected.*

—**Mark Schoeberl** [Science and Technology Corporation—*Chief Scientist and Former Aura Project Scientist*]

HIRDLS—with its high vertical resolution—has made a unique contribution to understanding the processes controlling global ozone distribution, with its ability to track phenomena such as *gravity waves*—atmospheric waves that propagate up into the atmosphere, as shown in **Figure 2**. Even small-scale waves, such as those generated by air traveling over mountains, play a role in the global circulation. Observations to quantify the role of several types of waves—from gravity waves to planetary waves—lead to improvements in the general circulation models used to understand ozone trends, assess compliance with the Montreal Protocol, and make ozone recovery forecasts.

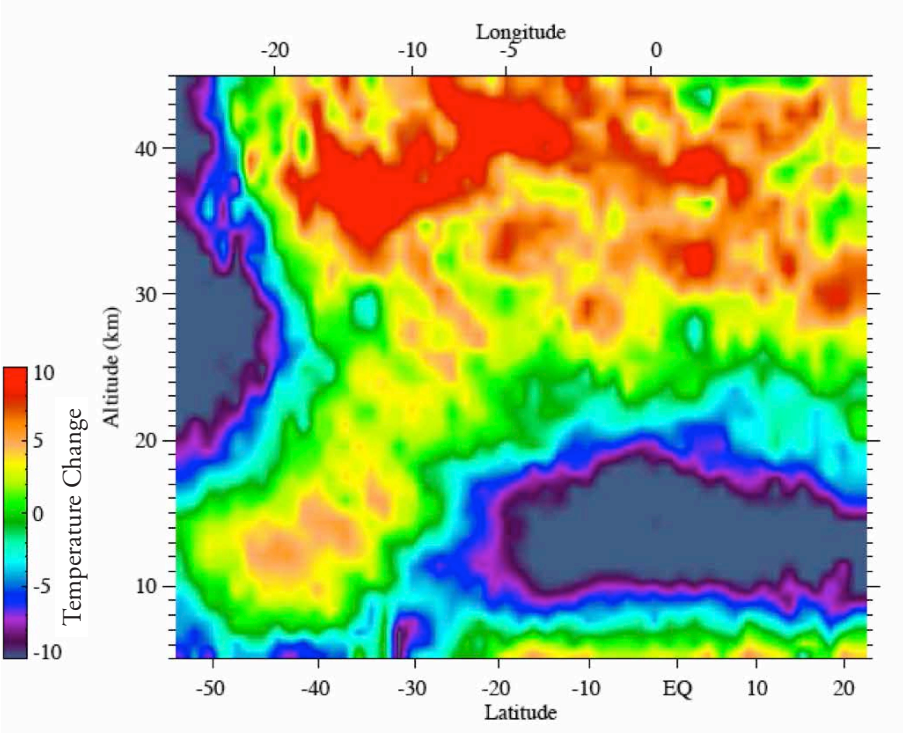



**Figure 2.** One of the pioneering capabilities of HIRDLS was its ability to observe smaller-scale waves in the atmosphere from space. In this example from June 2005, HIRDLS observed a *gravity wave*. The differential temperature cross-section over South America depicts a pattern of alternating series of positive and negative wave fronts propagating from mid-latitude (~45° S) tropopause toward the midstratosphere tropics (~15° N). This gravity wave has short vertical [~4-km (~2.5-mi)] and horizontal [500-km (~311-mi)] wavelength and small temperature amplitude (1-2 K) that cannot be observed with other remote sensing techniques. **Image credit:** H. Lee and J. Gille, National Center for Atmospheric Research (NCAR)

HIRDLS has also detected intrusions of ozone-rich stratospheric air into the upper troposphere, a step towards quantifying the contributions of stratospheric ozone to tropospheric ozone levels. Simulations using the Goddard Earth Observing System Model, Version 5 (GEOS-5) Chemistry and Transport Model reproduced events observed by HIRDLS, demonstrating the ability to anticipate these stratospheric intrusion events that routinely influence the upper and middle troposphere and occasionally reach the lower troposphere. These results suggest that in order to improve the accuracy of the forecasts they make, air quality models may need to account for these intrusions.

*Aura has been a central and unifying focus for atmospheric science since the time I first began atmospheric remote sensing research. It was the obvious follow-on mission to TOMS, UARS, and SAGE-II for stratospheric science, and brought NASA much more strongly into global tropospheric research. When combined with the other atmospheric observations within the A-Train, Aura has revolutionized the scientific understanding of atmospheric processes.*

—**Ken Jucks** [NASA Headquarters—*Aura Program Manager*]

*Air Quality*

Detecting atmospheric composition in the troposphere from space, such as the chemicals classified as the EPA's Criteria Pollutants, has been a challenge because near-ground amounts are in the parts-per-billion to parts-per-million (ppb - ppm) range, and therefore difficult to detect through the overlying atmosphere. NASA, while not directly involved with regulation, is providing a consistent, global, space-based view of when and where air pollution occurs. Several European satellites have been used to track pollution, but OMI's and TES's powerful detectors/spectrometers, high spatial (urban-scale) resolution, and advanced algorithms have sufficient quality to be highly

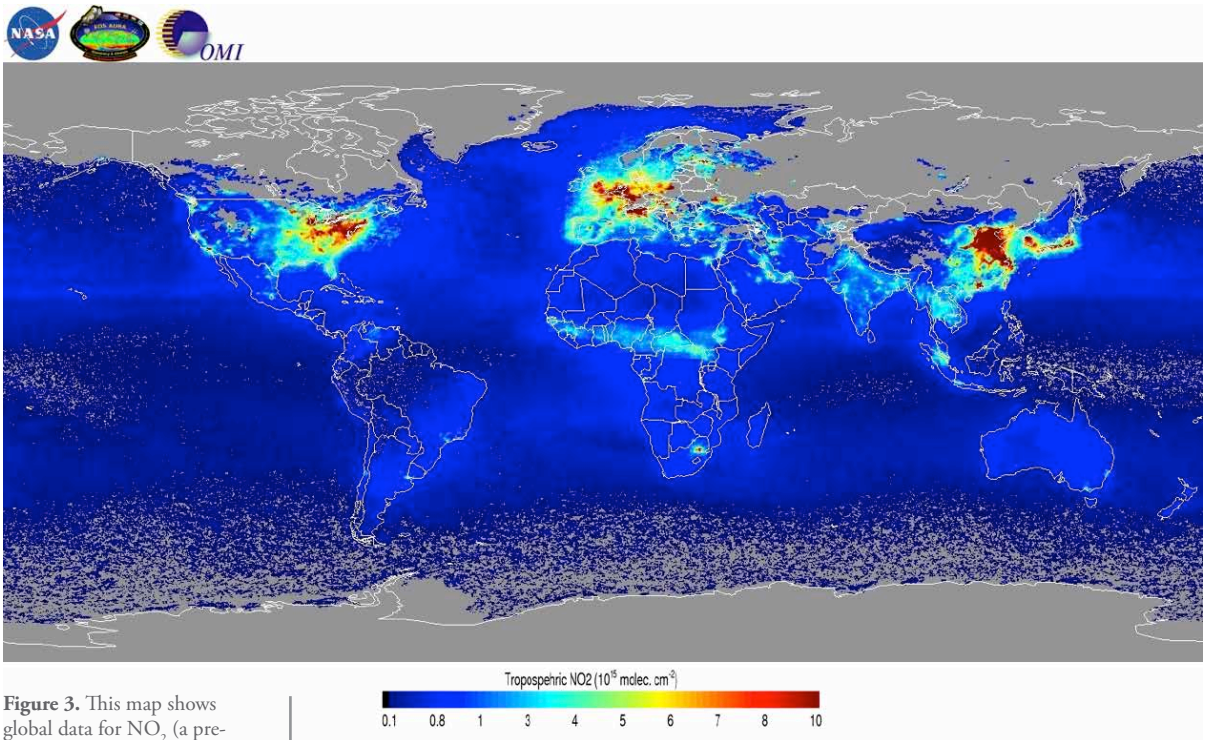



**Figure 3.** This map shows global data for $NO_2$ (a precursor to ozone pollution) from OMI for January 2005. Spatial and temporal averages yield a resolution of 0.25° latitude/longitude. Global pollution "hotspots" clearly show up in the Eastern U.S., Europe, and China. The high values in the Sub-Sahara are from agricultural burning. Emissions from some cities in South America, South Africa, and Australia are also revealed. **Image credit:** NASA

useful for air quality applications that benefit human health. The WMO reports that over two-million deaths per year are the result of poor air quality. Using information from Aura, air quality scientists and policymakers could, for the first time, see pollution on regional and continental scales at high spatial resolution. After the first year in orbit, Aura was able to locate pollution "hotspots" over large industrialized cities; areas of large agricultural burning could also be detected—see **Figure 3**. With improved algorithms and Aura instrument calibration since launch, new data are emerging that demonstrate how emissions have changed over time and how far pollution can travel.

For example, Beijing's poor air quality has been reported frequently in the media and in 2008 there was much concern about air quality during the Beijing Olympic Games. In August 2008, Chinese officials took extreme measures to improve the city's air quality by restricting auto traffic and power plant emissions prior to and during the games. OMI observations tracked the dramatic improvement of air quality—see **Figure 4**—in comparison with previous years.

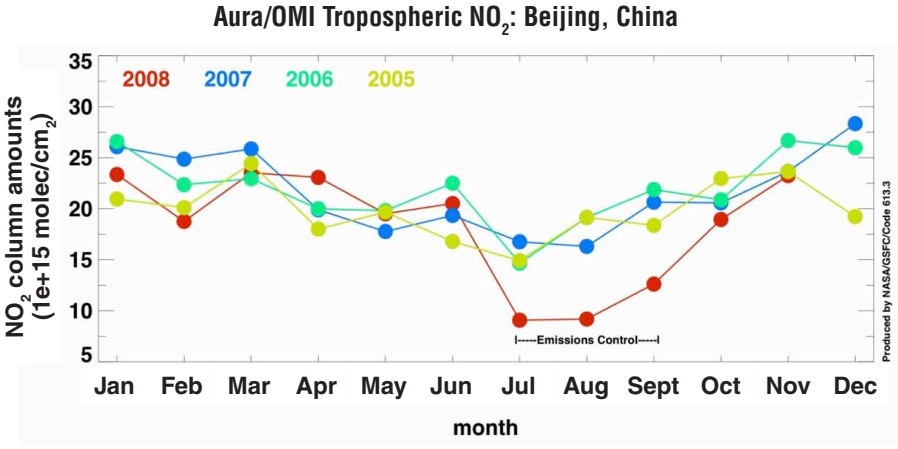



**Figure 4.** This graph shows monthly OMI observations of $NO_2$ over Beijing for 2005, 2006, 2007, and 2008. Controls were put into effect a month prior to the start of the Olympics in August 2008; their effectiveness is reflected in the steep decline to levels that extended until after the Games' completion, at which time levels increased to historical levels. Plots for other years show the normal annual cycle. **Image credit:** J. Witte, NASA/SSAI

Once the restrictions were abandoned, however, air quality quickly reverted to the usual levels. Ongoing Aura measurements show that pollution continued to rise over all of China. **Figure 5a** plots the trends over Eastern China for both $NO_2$ and $SO_2$. The increase in $NO_2$ is likely due to increased transportation emissions. The decrease in $SO_2$—despite China's continued building of power plants—is likely due to increased use of scrubbers for plant emissions. The observed reductions in $SO_2$ rebuts the speculation that China's pollution could have caused the so-called "hiatus" in global warming trends over the last 14 years, as $SO_2$-generated aerosols reflect light, resulting in cooling.

On the other side of the globe, satellite data indicate that pollution controls regulating emissions from power plants over the U.S. have significantly reduced both $SO_2$ and $NO_2$ over the Eastern U.S. as shown in **Figure 5b**[6]. The $SO_2$ decrease has direct bearing on acid rain, which has dropped considerably as regulations have gone into effect. The EPA and local environmental protection agencies have long relied on a limited number of ground sites to assess regulation effectiveness.

Ozone pollution's global reach can also be observed from TES and OMI measurements. TES tracked tropospheric ozone originating over Eastern China, which was picked up by westerly winds in the spring months. The ozone measurements correlate well with TES and MLS CO measurements. CO is a by-product of combustion and a chemical precursor of ozone. Since the most likely sources of combustion in urban areas are anthropogenic, the heightened levels of ozone are likely linked to human activities.

*The observed reductions in $SO_2$ rebuts the speculation that China's pollution could have caused the so-called "hiatus" in global warming trends over the last 14 years, as $SO_2$-generated aerosols reflect light, resulting in cooling.*

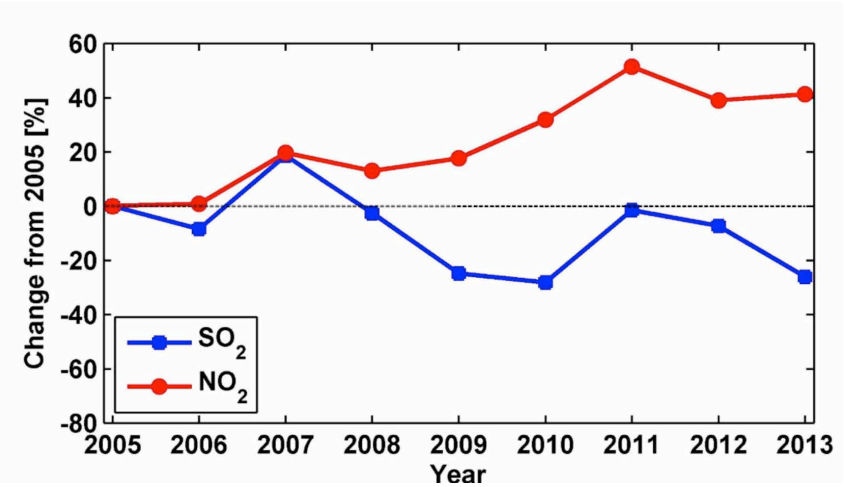



**Figure 5a.** Trends in OMI $SO_2$ and $NO_2$ observations for China from 2005 to 2013. Red circles indicate $NO_2$; blue squares, $SO_2$. $NO_2$ shows an on-average increase over time, while $SO_2$ shows a slight decline. **Image credit:** C. Mclinden, Environment Canada

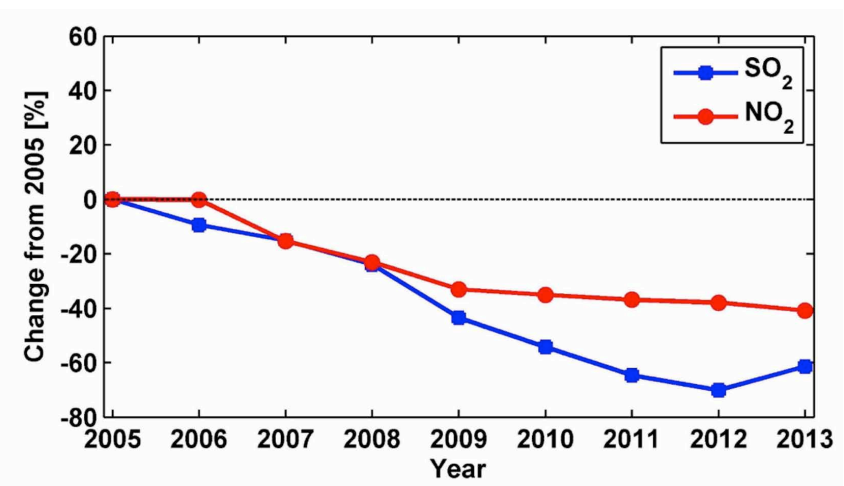



**Figure 5b.** Trends in OMI $SO_2$ and $NO_2$ observations for the Eastern U.S. from 2005 to 2013. Both $SO_2$ and $NO_2$ show a steady decline. **Image credit:** C. McLinden, Environment Canada

[6] A more detailed discussion of the $NO_2$ pollution decrease over the U.S. can be found at *www.nasa.gov/content/goddard/new-nasa-images-highlight-us-air-quality-improvement/#.U8acpChLIjN*. A similar discussion for $SO_2$ can be found at *www.earthobservatory.nasa.gov/IOTD/view.php?id=76571*.

Analysis of OMI data also confirmed that China was the source of the pollution. **Figure 6** illustrates global tropospheric ozone, with high ozone levels at mid-latitudes in the Northern Hemisphere, roughly corresponding to the location of the westerly jet stream. This is also the latitude of the highest concentration of cities and industrial zones in the Northern Hemisphere. Of equal concern is that pollution from the U.S. is adding to background levels of ozone over Europe. Note that there is a correlation with distributions of $NO_2$ levels (see Figure 3).

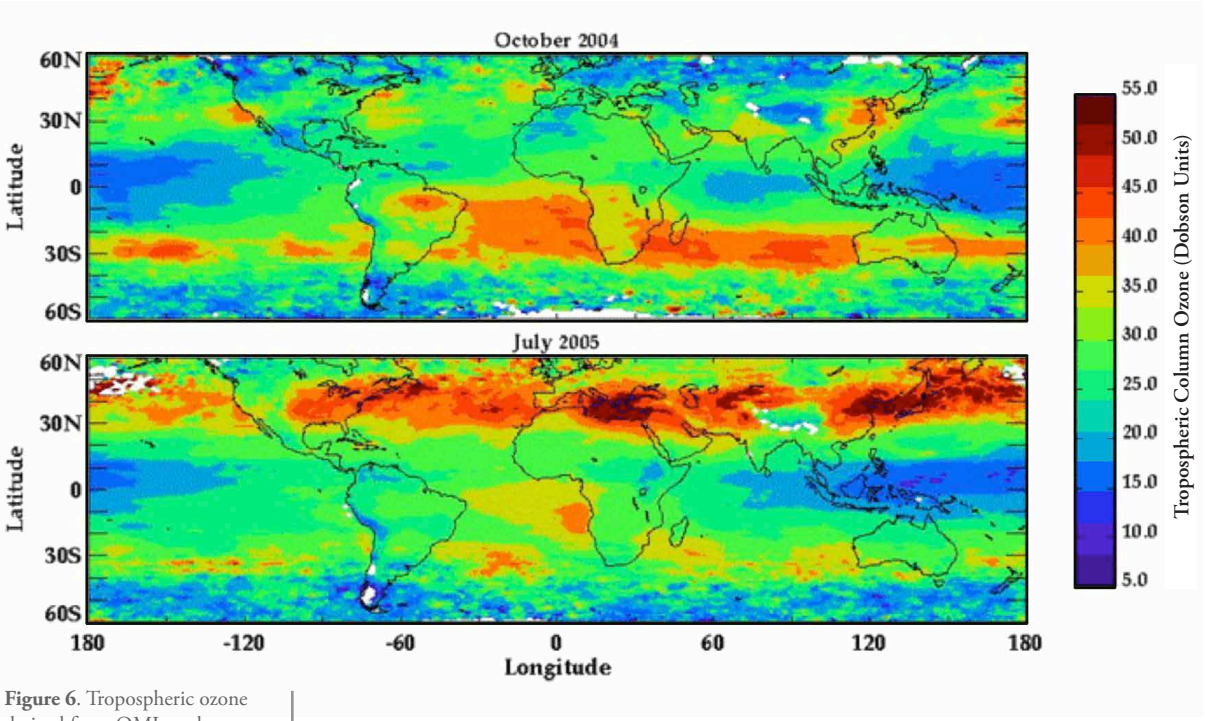



**Figure 6**. Tropospheric ozone derived from OMI total ozone minus MLS stratospheric ozone. The band of high ozone (lower map) at northern mid-latitudes that appears annually in the spring and summer results from anthropogenic activity and the persistent westerlies. The band of high ozone (upper map) in the South Atlantic and Indian Oceans results from agricultural burning in South America and Africa. **Image credit:** J. Ziemke NASA/USRA

*"Emissions reductions have an immediate and profound impact on local concentrations of $SO_2$."*

— **Russ Dickerson** [University of Maryland, College Park—*NASA's Air Quality Applied Science Team (AQAST)*]

Aura capability for detecting pollution is reflected in the 10-year air quality record over the Canadian oil sands by OMI and TES. The emissions come from excavators, dump trucks, extraction pumps and wells, and refining facilities where the oil sands are processed. OMI clearly detects increased levels of $NO_2$ and $SO_2$ comparable to levels from a medium-sized city or large power plant. The rate of increase of $NO_2$—about 10% per year—is higher than the Canadian National Pollutant Release Inventory, while for $SO_2$ it is lower. TES data are being used to examine trends in volatile organic compounds from oil extraction operations.

*"It's really important that we start to take our air quality policies beyond the state and national levels and start to think about air quality on an international level."*

—**Daniel Jacob** [Harvard University—*AQAST*]

In a different application, OMI is able to measure formaldehyde (HCHO), a volatile organic compound (VOC) that is emitted from both natural (e.g., isoprene from trees) and "manmade" sources (e.g., automobile exhaust). Along with $NO_2$, it is a precursor to ozone. Since 1980 regulations have been established to reduce the amount of "manmade" VOCs in order to reduce the production of unhealthy ozone. Studies using OMI data show that the ratio of HCHO to $NO_2$ can help air quality managers

identify regions of reduced surface ozone, likely reflecting the effectiveness of regulations. These results indicate that $NO_2$ reduction is key to lowering pollution in regions where HCHO has a natural source.

While classified as a research product at launch, ammonia ($NH_3$) is now classified as a Standard Product due to the successful effort to retrieve $NH_3$ from the TES spectra. $NH_3$ impacts soil acidification, biodiversity, and the nitrogen cycle. It is also involved in the formation of atmospheric $PM_{2.5}$, which has adverse health effects. Animal agriculture accounts for most of the manmade $NH_3$ produced in the U.S.; however, the uncertainty in the magnitude and seasonality of $NH_3$ emissions hampers the development of control measures. That said, new TES data may well lead to additional regulations.

As noted, Aura air quality data are expected to provide an advantage for forecasters and regulators. Several presentations at the tenth anniversary Science Team Meeting described how this advantage would be applied. These include a study to provide the air quality community with a multiyear global chemical and aerosol reanalysis using Aura and other A-Train measurements; regional chemical data assimilation experiments to quantify the influences of changes in $NO_2$ emissions on U.S. air quality during the Aura era; a test of the utility of satellite data for air quality assessment activities using the Regional Air Quality Modeling System (RAQMS); and assimilating all the tropospheric constituents measured by Aura plus CO and aerosols measured by the Atmospheric Infrared Sounder (AIRS) and the Moderate Resolution Imaging Spectroradiometer (MODIS), respectively, both on Aqua.

*Early in the mission, Aura data were used to challenge scientists who had put forth the Iris Hypothesis, which claims that feedback processes would offset greenhouse warming. However, MLS data refuted that idea, showing that the feedbacks actually reinforced heating, thereby further warming the planet.*

Another study underway is the application of the U.S. EPA's Community Multiscale Air Quality (CMAQ) model. This model is a powerful computational tool used by the EPA and several states for air quality management, the results of which are used by several federal and state agencies in their air quality planning and regulation. Preliminary tests show that using Aura data obtained over Maryland locations can improve CMAQ predictions.

There are other uses for OMI data beyond climate change studies (see below) and air quality regulation. For example: aviation safety after a volcanic eruption. Volcanic ash plumes can cause serious concerns for aircraft operations, as demonstrated during recent eruptions in Iceland and Alaska. OMI $SO_2$ data, which are proxy to volcanic ash, are processed and released in near-real time and made available for airline operations. Many more examples of OMI applications appear on the Aura website at *aura.gsfc.nasa.gov/science/index.html*.

*Climate*

Aura measures carbon dioxide ($CO_2$), methane ($CH_4$), water vapor, clouds, aerosols, and ozone—all of which contribute to climate change. Clouds and aerosols may either enhance or diminish global warming, depending on their altitude and other characteristics such as optical depths. They may also interact with each other and thereby change their warming or cooling effects. Despite lacking the precision and spatial coverage of NASA's OCO-2 or JAXA's Greenhouse Gases Observing Satellite (GOSAT) for these species, Aura data have helped untangle these complex interactions, making broad contributions to climate science.

Early in the mission, Aura data were used to challenge scientists who had put forth the *Iris Hypothesis*, which claims that feedback processes would offset greenhouse warming. However, MLS data refuted that idea, showing that the feedbacks actually reinforced heating, thereby further warming the planet. As MLS is only able to detect

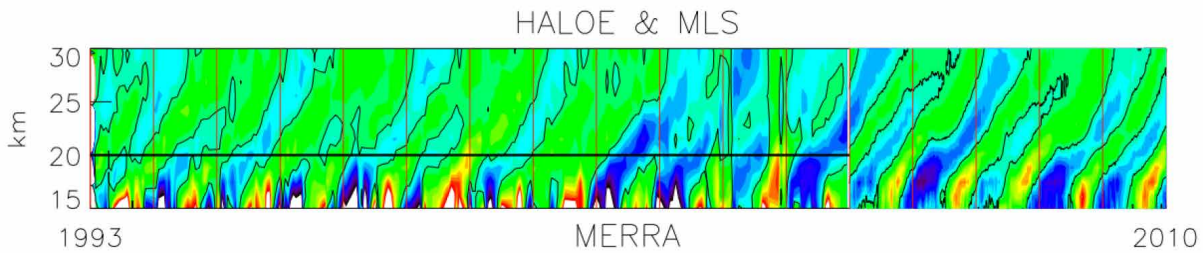



**Figure 7**. Water vapor zonally averaged anomalies at the Equator from 1993 to 2010. HALOE data end in 2005; MLS data are used from 2005 to 2010. Data are represented as anomalies (deviation from the mean), ranging from -2 ppmv (blue) to +2 ppmv (red). Notice the alternating highs and lows resulting from the seasonal cycle of deep convection zones that modulate the amount of water entering the stratosphere. **Image credit**: Schoerberl *et al.,* ACP 2012

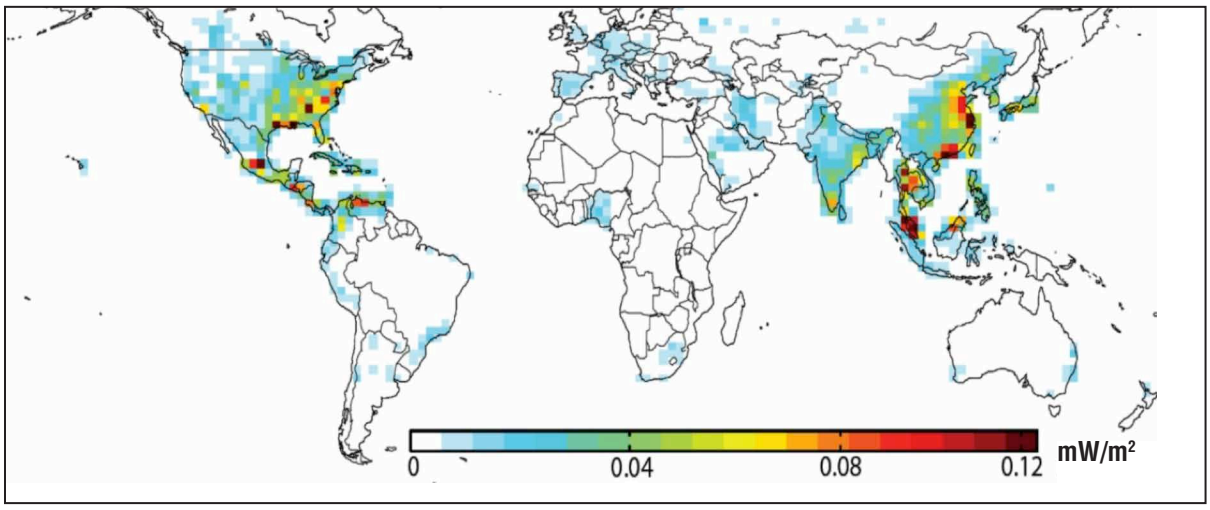
ice clouds, HIRDLS observes both water and clouds, leading to supporting results. Subsequently, data from CloudSat further confirmed the Aura result.

Since water vapor is the most abundant greenhouse gas, knowing its concentration throughout the atmosphere is very important to understanding the water cycle. Since TES measures different hydrogen isotopes in water, measurements of the isotopic ratios at different locations indicate the source of the water evaporation and where it rains out, and how much water vapor condenses over various locations on Earth. This is an important aspect of the hydrological cycle, used in climate models that have been tested by TES data.

An equally important issue is spatial and temporal water vapor trends near the tropopause, where it is difficult to discern small long-term trends from decadal-length datasets. A combination of Aura/MLS and UARS/Halogen Occultation Experiment (HALOE) likely represent the best dataset ever collected—see **Figure 7**. Neither models nor the combined HALOE and MLS data show any long-term trends in the tropical 100-hPa (100-mb) water vapor concentration. Prominent in this figure are the alternating highs and lows resulting from the seasonal cycle of deep convection zones that modulate the amount of water entering the stratosphere. Once in the tropical stratosphere, these seasonal anomalies move slowly upward. This effect and other short-term variations need to be carefully accounted for in order to detect a water vapor trend.

Another example of an Aura contribution to climate research is the use of TES measurements to calculate the amount of heat ozone absorbs in Earth's atmosphere. When combined with chemical transport models, results show a variation in trapped heat by a factor of 10, depending upon the location of the ozone-forming chemical emissions, illustrating the importance of knowing the variability of tropospheric ozone—see **Figure 8**—and particularly for climate model projections. Quantifying the amount of heat trapped spatially and temporally was an important input to the IPCC's AR5, where TES tropospheric ozone data constrained various atmospheric-chemistry-climate models used to calculate radiative forcing and to bring them into better

**Figure 8.** Contributions of $NO_2$ emissions—a major precursor for ozone—to the global average thermal absorption of ozone in the troposphere as observed by TES in August 2006. High values (red and orange shades) indicate that emissions in that location contribute more strongly to the trapping of heat in Earth's atmosphere relative to other locations. **Image credit**: NASA/JPL and University of Colorado



agreement. Complementary to these findings are the long-term OMI measurements of tropospheric ozone, where it is a greenhouse gas and a pollutant, indicating a slight trend upward during the Aura measurement era. Before this time, measurements were too sparse to draw any conclusions about trends.

*Solar irradiance*

Solar spectral irradiance (SSI) is not an OMI Standard Product, but is required for calculating OMI's atmospheric composition products. SSI is responsible for the formation of ozone, and therefore then becomes a climate variable over the long term; however, trends in SSI are very difficult to measure because of instrument calibration requirements. OMI's 10-year stability, when combined with the short-term spectral irradiance associated with the 28-day solar rotation, allows determination of UV solar irradiance trends over the 11-year solar cycles. OMI's solar rotation data agree very well with data from Eumetsat's Global Ozone Monitoring Experiment-2. The recent study shows that solar irradiance variations between 280 nm and 340 nm are smaller than those measured by SORCE, but agree better with the Naval Research Laboratory's SSI model. There are ongoing discussions of this important result between the OMI and SORCE teams.

**Aura Data Product Validation**

The science results presented in the previous section require rigorous *validation* activities. Aura's measurements have been compared to ground-based, *in situ,* and other satellite measurements of the same property at the same approximate place and time, under a variety of atmospheric conditions to ensure long-term stability of the instruments. This was done during the Aura *prime mission* period—i.e., the first five years—with ground and balloon measurements, aircraft campaigns, comparisons with other satellites, and even comparisons between Aura instruments. Aura validation requirements are found at *avdc.gsfc.nasa.gov/PDF/Aura_validation_needs_update_v1.0.pdf*.

Validation requirements have continued to evolve, in part because additional data products have been developed and also as calibration updates. Validation efforts have continued throughout the life of the mission (albeit with less frequency after the prime mission period) to demonstrate long-term accuracy of the instruments.

Aura has established a dedicated Aura Validation Data Center (AVDC) that is unique among EOS missions (see *avdc.gsfc.nasa.gov*). The AVDC supports Aura validation and science activities, and some validation activities for other A-Train satellites. Its archives include data from the Aura validation campaigns, NASA aircraft and balloon deployments, and established ground networks that collect atmospheric composition data. The AVDC also links to European satellite validation archives and provides user tools for data collecting, subsetting, formatting, visualizing, and archiving of validation data. A unique capability for the AVDC is instrument field-of-view (FOV) predictions: The Center provides 16-day instrument FOV predictions for the Aura OMI, MLS, and TES instruments, as well as subsatellite points for instruments on A-Train satellites and the Terra platform, where these data are updated on a daily basis.

Such validation efforts enabled the instrument teams to quantify precision, resolution, and systematic errors of their products. For every Aura data product tested, validation has shown that each product met or exceeded its proposed accuracy and precision specification. Through 2008 there were over 70 papers related to Aura validation, including a special section of the *Journal of Geophysical Research* (*doi:10.1029/2007JD009602*).

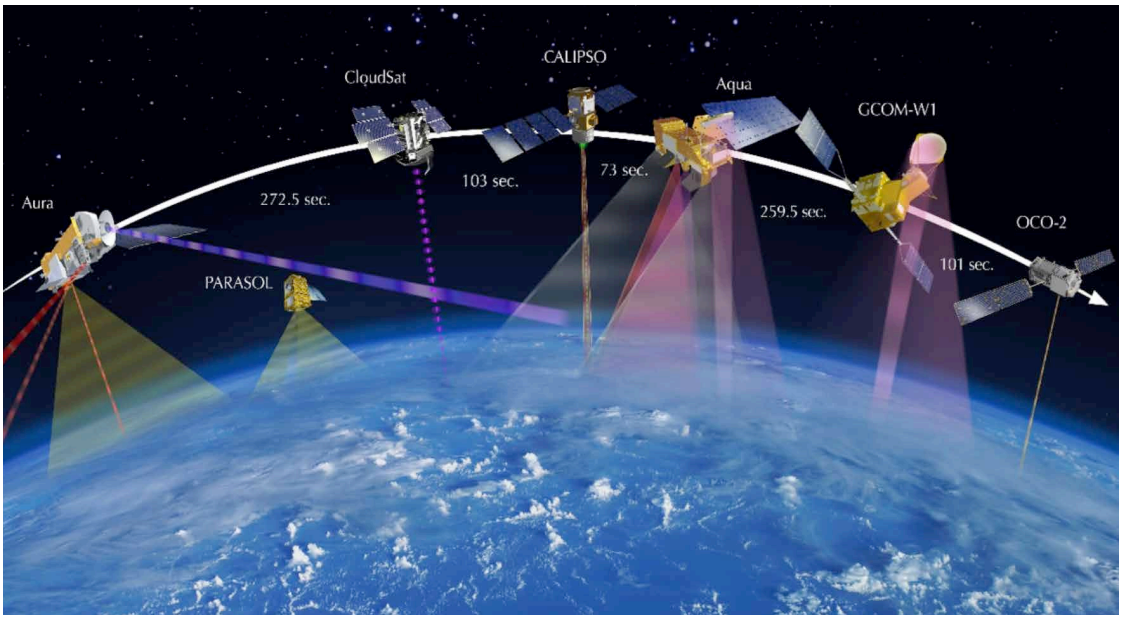
*Aura has established a dedicated Aura Validation Data Center (AVDC) that is unique among EOS missions. The AVDC supports Aura validation and science activities, and some validation activities for other A-Train satellites. Its archives include data from the Aura validation campaigns, NASA aircraft and balloon deployments, and established ground networks that collect atmospheric composition data.*

feature articles

## Aura and the A-Train: Science Synergy

When Aura was launched it joined Aqua in what later became known as the Afternoon Constellation, or A-Train, of satellites*. At first, Aura flew 15 minutes behind Aqua, and their coincident orbital tracks allowed them to take advantage of their respective capabilities to make coordinated and near-coincident measurements of clouds, aerosols, and other key parameters related to Earth's climate. The effects of clouds and aerosols and their interaction on each other remain one of the largest uncertainties in climate models. In addition, the synergy of the A-Train measurements led to improved Aura data products.

The Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from Lidar (PARASOL) spacecraft, became part of the A-Train when it was launched in late 2004 and the CloudSat and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) missions joined when they were launched together in 2006. In 2007 Aura's position in the formation was changed to enable high-quality, merged data products. This followed careful analysis by NASA's Mission Operations Working Group (MOWG) to ensure that there would be no harmful impact on satellite fuel reserves, planned mission lifetimes, ground station operations, and that the more compact "train" could be controlled. Subsequently, Aura and other A-Train instrument teams gave their approval for the maneuver. Aura's current configuration in the A-Train, now only eight minutes behind Aqua, was achieved in the spring of 2008. The Japan Aerospace Exploration Agency's (JAXA) Global Change Observation Mission - Water (GCOM-W1) mission joined the formation in 2012. The second Orbiting Carbon Observatory (OCO-2), launched in 2014, now leads the formation slightly ahead of Aqua. PARASOL was removed from the A-Train in 2009.




This graphic depicts the order of A-Train satellites after the launch of OCO-2 launch in July 2014. The constellation consists of [front (right) to back (left)] OCO-2, GCOM-W1, Aqua, CALIPSO, CloudSat, and Aura. The entire A-Train passes over any given surface location in 13.5 minutes. PARASOL has drifted out of the A-Train. Glory (intended to collect data on Earth's energy balance) was to have been part of the A-Train, but it failed to reach orbit after its 2011 launch. **Image credit:** NASA

Provided here is just one example of how A-Train synergy was employed to uncover the complexities of aerosol-cloud interaction using MLS cloud ice amount and carbon monoxide (CO; an indicator of pollution) data, Aqua/MODIS cloud ice particle size, and TRMM (not in the A-Train) precipitation amounts. The question was: *How does pollution affect precipitation and, subsequently, climate?* MLS's unique capability to observe CO within the clouds combined with MODIS data show that clean clouds have larger ice particles. Precipitation as measured by TRMM was shown to be greater for clean clouds and lower for dirty clouds. These results provided controls on model calculations that employ cloud water content and water vapor for climate predictions.

* For more details on the A-Train please read "Taking the A-Train to New Orleans" in the January-February 2011 issue *of The Earth Observer*, [**Volume 23, Issue 1**, pp. 12-23].

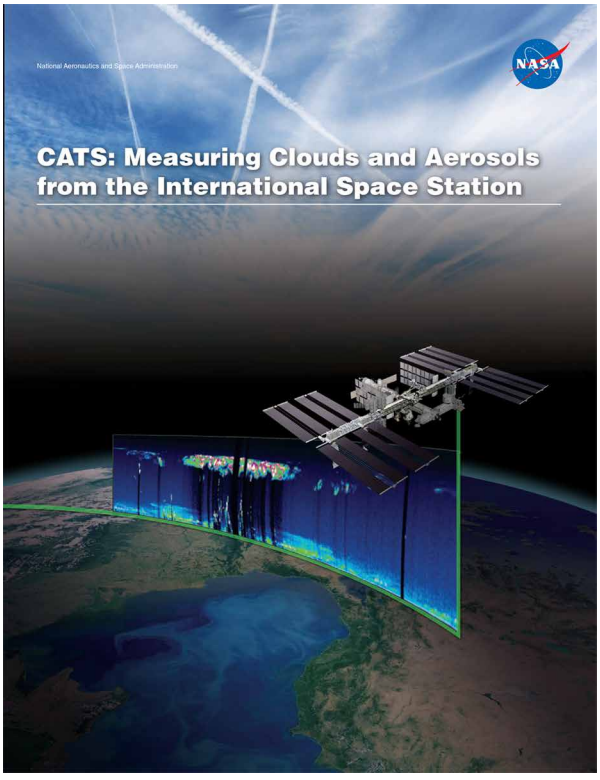
**Summary and Prospects**

This article has presented just some of the many discoveries that have come from Aura over the past 10 years. To date, the mission has met or surpassed nearly all mission success criteria. Aura data are being used in the U.S. Global Change Research Program and three international assessments—the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, the World Meteorological Organization and United Nations' Environmental Program Scientific Assessments of Ozone Depletion, and the Task Force on Hemispheric Transport of Air Pollution. Aura's data have proven to be valuable for air quality applications such as identifying the trends that result from regulation of emissions on decadal time scales, and shorter time scale applications are being assessed. The original Aura science questions have surely been addressed or answered and serendipitous discoveries have been realized. Although HIRDLS is no longer operational and the TES instrument shows signs of wear that have limited its operations, OMI and MLS continue to operate well. OMI's highly successful advanced technology has been and will continue to be employed by new NASA satellite instruments, such as on the Suomi National Polar-orbiting Partnership (NPP) Ozone Mapper Profiling Suite (OMPS) and on the Tropospheric Emissions: Monitoring of Pollution (TEMPO[7]) instruments. Overall, the Aura mission continues to operate satisfactorily and there is enough fuel reserve for Aura to operate safely in the A-Train until 2023. ■

[7] See "NASA Ups the TEMPO on Monitoring Air Pollution" in the March–April, 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 2**, pp. 10-15].

## CATS Mission Brochure Available Online

Scheduled to launch on December 16, 2014, NASA's Clouds and Aerosol Transport System (CATS) mission will provide vertical profiles of cloud and aerosol properties at three wavelengths (1064, 532, and 355 nm) from its mounting location onboard the International Space Station. Data from CATS will be used to derive a variety of properties of cloud and aerosol layers including: backscatter, layer height, layer thickness, extinction, optical depth, and at least a coarse discrimination of aerosol and cloud type (e.g., smoke, dust, pollution, water droplet, ice crystal).




The mission seeks to build on the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) data record, provide observational lidar data to improve research and operational modeling programs, and demonstrate new lidar retrievals of clouds and aerosols from space. These technologies and the science gained from the CATS mission will be used to design future missions that will study clouds and aerosols and their affects on Earth's climate and air quality for years to come.

For more information about CATS, please refer to the mission brochure online at *eospso.gsfc.nasa.gov/sites/default/files/publications/ISS-CATS_Final_508.pdf* or visit *cats.gsfc.nasa.gov*.

blog log

# Blog Log

*Heather Hanson, NASA's Goddard Space Flight Center/Global Science and Technology Inc., heather.h.hanson@nasa.gov*

This periodic installment features entries in blogs related to NASA's Earth-science research and fieldwork, and provides links to access the respective full blogs and view color photographs online. In this issue, we highlight four recent entries in NASA's *Notes from the Field* blog.

If you know of any blogs that should be shared in the Blog Log—perhaps one of your own—please email Heather Hanson at *heather.h.hanson@nasa.gov.*

[Blog introductions are modified from text in the featured blogs, which are also the sources for the images provided here.]

## Hurricane and Severe Storm Sentinel 2014

**Mary Morris**, a graduate student studying atmospheric science at the University of Michigan, welcomes you to the Hurricane and Severe Storm Sentinel (HS3) blog. Morris has been posting about her experiences participating in the HS3 mission at NASA's Wallops Flight Facility.

HS3 is a mission designed to investigate the processes that control hurricane formation and intensification. In order to collect observations of hurricanes, the team uses unmanned aerial vehicles (UAVs) that can fly for long distances to reach hurricanes and storms forming in the Atlantic Ocean basin, and are outfitted with suitable meteorological instruments.

Sitting under the WB-57, **Mary Morris** hides from the hot Florida sun to download data from the day's flight. **Image credit:** NASA

To learn about the science flights through Hurricane Cristobal and Hurricane Gonzalo and some of the challenges the team has faced, visit *earthobservatory.nasa.gov/blogs/fromthefield/category/hs3-2014*.

## NASA in Alaska 2014

In 2014, a variety of NASA aircraft associated with different airborne campaigns have been flying over Arctic forests, sea ice, glaciers, permafrost, vegetation, lakes, volcanoes, and other terrestrial locations in Alaska. For example, from early July through mid-August 2014 scientists flew low over the treetops of interior Alaska to get a first-of-a-kind look at the state's forests with a portable, airborne imaging system called Goddard's Lidar, Hyperspectral, and Thermal Airborne Imager (G-LiHT) to map the composition, structure, and function of the ecosystem.

Also in 2014, NASA scientists, engineers, the ER-2 team, and others flew a laser altimeter called the Multiple Altimeter Beam Experimental Lidar (MABEL) over melting summer sea ice and glaciers to get a preview of what these polar regions will look like with data from the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) mission—scheduled for launch in 2017.

In addition, a new NASA airborne campaign—known as the Arctic Radiation IceBridge Sea and Ice Experiment (ARISE)—took measurements to help researchers better understand the role that clouds play in Arctic warming as sea ice conditions change. To learn more about NASA's Arctic adventures, visit *earthobservatory.nasa.gov/blogs/fromthefield/category/nasa-in-alaska-2014/page/4.*

### Ship-Aircraft Bio-Optical Research

In July 2014 scientists with NASA's Ship-Aircraft Bio-Optical Research (SABOR) experiment started making observations from sea-surface and airborne vehicles off the U.S. Atlantic Coast, aimed at advancing the technology needed to measure microscopic plankton in the ocean from space. This blog allows you to follow SABOR researchers for three weeks as they work toward finding out how and why plankton concentrations are changing around the planet. Plankton play an important part of the climate system and deliver oxygen to the atmosphere, absorb carbon dioxide, and form the base of the marine food chain. To learn more and to read about the adventures on deck, visit *earthobservatory.nasa.gov/blogs/fromthefield/category/ship-aircraft-bio-optical-research-sabor*.

The SABOR science team onboard the Research Vessel Endeavor. **Image credit**: NASA SABOR/Wayne Slade, Sequoia Scientific

### The Langley Aerosol Research Group Experiment 2014

As part of a project called the Langley Aerosol Research Group Experiment (LARGE), a group of scientists at NASA's Langley Research Center are studying the chemical, optical, and microphysical properties of atmospheric aerosols and their effects on air quality and climate. One team goal is to assess the distribution of aerosols and their impacts on hurricanes. To read about the many other exciting experiments with their extremely broad objectives and applications, visit *earthobservatory.nasa.gov/blogs/fromthefield/category/large-2014*.

View of the northeast quadrant of 2014's Hurricane Cristobal from one of the National Oceanic and Atmospheric Administration's hurricane hunter aircraft. **Image credit:** NASA

meeting summaries

# 2014 HyspIRI Product Symposium Summary

*David Landis, NASA's Goddard Space Flight Center/Sigma Space Corporation, david.r.landis@nasa.gov*
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*Lisa Henderson, NASA's Goddard Space Flight Center/Sigma Space Corporation, lisa.henderson@nasa.gov*

**Introduction**

The Hyperspectral Infrared Imager (HyspIRI) satellite-based mission will study the world's ecosystems and provide critical information on natural disasters such as volcanoes, wildfires, and drought. Data from HyspIRI will be used for a wide variety of studies primarily in the role of the carbon cycle in ecosystem processes, and Earth surface and interior phenomena.

The mission will provide a benchmark on the state of the world's ecosystems, against which future changes can be assessed. The mission will also assess the pre-eruptive behavior of volcanoes and the likelihood of future eruptions, as well as the carbon and other gases released from wildfires.

HyspIRI will operate in low-Earth orbit, and includes two instruments: an imaging spectrometer that will take measurements from visible to short-wave infrared (VSWIR) wavelengths in contiguous 10-nm bands between 380 and 2500 nm, and a multispectral imager that will take measurements in the mid- and thermal-infrared (TIR) region of the spectrum between 3 and 12 µm. The VSWIR and TIR instruments both have a spatial resolution of 60 m (~197 ft) at nadir. The VSWIR spectrometer will have global coverage every19 days; the TIR instrument will have global coverage every 5 days (due to a larger swath width). HyspIRI also includes an Intelligent Payload Module (IPM), which will enable direct broadcast of a subset of the data for immediate needs, such as disaster aid.

The mission was recommended as a *Tier 2* priority in the 2007 National Research Council Decadal Survey that was requested by NASA, the National Oceanic and Atmospheric Administration (NOAA), and U.S. Geological Survey (USGS). HyspIRI is in the Pre-formulation Phase of its development, and has not had an official launch date assigned. Additional information on the mission may be found at the HyspIRI website at *hyspiri.jpl.nasa.gov*.

**Meeting Overview**

More than 120 scientists gathered on June 4-5, 2014, for the fourth annual HyspIRI Product Symposium at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD. This year's symposium theme was *HyspIRI: Enabling the Evolution of Land Imaging with New Approaches and Products,* with a special focus on understanding how HyspIRI data can help address sustainable land-imaging requirements.

The symposium incorporated seven sessions that addressed:

- HyspIRI's evolving mission and products;
- compatibility with other U.S. missions and the Sustainable Land Imaging (SLI) initiative;
- ecosystem studies and aquatic ecology;
- public health and disasters;
- new HyspIRI-like datasets, instrument and data calibration issues, and product validation;
- the IPM; and
- ground data processing and distribution.

The symposium included 41 presentations, 6 posters, and 2 demonstration sessions, with discussion of approaches to developing new potential products in land and coastal imaging. Owing to the depth and breadth of information provided at the workshop, only an upper-level summary will be provided here. The full workshop agenda, presentations, and speakers list are available at the HyspIRI symposium website at *hyspiri.jpl.nasa.gov/events/2014-hyspiri-science-symposium*.

**Day 1**

*Opening Comments*

The opening session, on *Evolving the HyspIRI Mission and Products,* began with **Betsy Middleton** [GSFC] giving an overview of the symposium. Then **Woody Turner** [NASA Headquarters (HQ)—*Program Scientist for Biological Diversity* and *Program Manager for Ecological Forecasting*] presented the 2014 guidance

study on the status of the HyspIRI mission and discussed current activities. **Steve Volz** [NASA HQ—*Associate Director for Flight Programs*[1]] provided an update on *NASA's Evolving Vision for Space* and described how the HyspIRI mission fits into that framework. **Rob Green** [NASA/Jet Propulsion Laboratory (JPL)] summarized the *Comprehensive Mission Report, 2008-2013.* **Jacqueline Lemoigne** [GSFC] discussed the challenges with the systems architecture for distributed spacecraft missions by identifying cost and risk implementation of future NASA missions. Finally, **Simon Hook** [JPL] talked about a *white paper* summary on the science impact of deploying VSWIR and TIR instruments on separate platforms (*hyspiri.jpl.nasa.gov/downloads/reports_whitepapers/HyspIRI-Separate-Platforms-Whitepaper-140722-1326.pdf*).

[1] As of November 2, 2014, Volz left NASA to lead NOAA's Satellite and Information Service (NESDIS).

*Technical Sessions*

**Petya Campbell** [University of Maryland, Baltimore County (UMBC)] chaired the first technical session, *HyspIRI's Compatibility with other U.S. Missions and the SLI initiative*; presentations in this session are summarized in **Table 1**. **Susan Ustin** [University of California, Davis] chaired the second session, on *HyspIRI's Scientific Products for Ecosystem Studies*, with presentations in this session summarized in **Table 2**. **Kevin Turpie** [UMBC] and **Jeff Luvall** [NASA's Marshall Space Flight Center (MSFC)], chaired the next sessions on *Aquatic Ecology, Public Health, and Disasters*, with presentations summarized in **Table 3**.

**Table 1: Day 1, Session 1 Technical Presentations:** HyspIRI's Compatibility with Other U.S. Missions and the SLI Initiative.

| Presenter(s) | Affiliation | Topic |
|---|---|---|
| **Del Jenstrom** and **Jeff Masek** | GSFC | Architecture study scope & methods/hyperspectral imaging and Sustainable Land Imaging (SLI) |
| **Ray Byrnes** | USGS | SLI for USGS |
| **Miguel Roman** | GSFC | Committee for Earth Observation Satellites (CEOS) Essential Climate Variables and SLI |
| **Jim Irons** | GSFC | Overview of Landsat 8 and the Operational Land Imager (OLI ) and Thermal Infrared Sensor (TIRS) |
| **Robert Wolfe** | GSFC | Overview of the Visible Infrared Imaging Radiometer Suite (VIIRS) and Moderate Resolution Imaging Spectroradiometer (MODIS) instruments |
| **Carlos Del Castillo** | GSFC | Pre-Aerosol, Cloud, and Ocean Ecosystem (PACE) mission |

**Table 2. Day 1, Session 2 Technical Presentations:** HyspIRI's Scientific Products for Ecosystem Studies.

| Presenter | Affiliation | Topic |
|---|---|---|
| **Fred Huemmrich** | UMBC | Retrieving light use efficiency (LUE) using Hyperion data and how this could be done with HyspIRI on a global scale |
| **Qingyuan Zhang** | UMBC | Retrieving the new fraction of incident photosynthetically active radiation absorbed by chlorophyll (faPARchl) product from space |
| **Ben Cheng** | Sigma Space Inc. | Retrieving gross primary production in forests and agriculture |
| **Ray Kokaly** | USGS | Vegetation feature analysis and spectral comparison using the USGS Processing Routines in IDL for Spectroscopic Measurements (PRISM) Software |
| **Philip Townsend** | University of Wisconsin | The Ecosystem Spectral Information System (EcoSIS) |
| **Saurabh Prasad** | University of Houston | Mapping fire scars using hyperspectral imagery and kernel based image analysis |
| **Wesley Moses** | U.S. Naval Research Lab (NRL) | Coastal remote sensing using the Hyperspectral Imager for Coastal Oceans (HICO*): Results, challenges and applications for HyspIRI |

*HICO flies onboard the International Space Station and is a special camera that separates light into hundreds of wavelengths to reveal details about the Earth's coasts, including water depth and visibility.

**Table 3. Day 1, Session 3 Technical Presentations:** Aquatic Ecology, Public Health, and Disasters.

| Presenter | Affiliation | Topic |
|---|---|---|
| **Wesley Moses** | NRL | HyspIRI Aquatic Studies Group (HASG) activities |
| **Joseph Ortiz** | Kent State University | Decomposition of hyperspectral data for use in Case 2 environments |
| **Arnold Dekker** | Commonwealth Scientific and Industrial Research Organisation (CSIRO) | Role of space borne imaging spectrometry in global water quality monitoring |
| **John Haynes** | NASA HQ | Health and air |
| **Stuart Frye** | Stinger Ghaffarian Technologies (SGT) | CEOS disaster risk management for societal benefit activities |
| **Rick Wessels** | USGS | Monitoring North Pacific volcanoes with near-real-time satellite data |
| **Mike Ramsey** | University of Pittsburgh | SLI requirements to monitor surface soil moisture with HyspIRI-like data |

**Day 2**

Day two started with **Rob Green** [JPL] and **Steve Ungar** [GSFC] chairing a session on *New HyspIRI-like Datasets and HyspIRI Calibration Topics*. Presentations in this session are summarized in **Table 4. Dan Mandl** [GSFC] chaired the next session, on *The Intelligent Payload Module (IPM)*, with presentations summarized in **Table 5**.

**Table 4. Day 2, Session 1 Technical Presentations:** New HyspIRI-like Datasets and HyspIRI Calibration.

| Presenter | Affiliation | Topic |
|---|---|---|
| **Ian McCubbin** | GSFC | An overview of the HyspIRI airborne campaign |
| **Rob Green** | JPL | Level 2 processing of the Airborne Visible/InfraRed Imaging Spectrometer (AVIRIS) HyspIRI preparatory campaign measurements |
| **Jorge Gonzales** | NOAA | HyspIRI flight campaigns for summer sea-land thermal gradients and sea-breezes in Los Angeles, CA |
| **Bo-Cai-Gao** | NRL | An overview on atmospheric correction of hyperspectral imaging data from aircraft and satellites |
| **Pat Cappelaere** | Vightel | A demonstration on getting processed satellite data onto smart phones and tablets using social media |
| **Rob Green** | JPL | Calibration and validation of AVIRIS Classic (C) and AVIRIS Next Generation (NG) |
| **Joel McCorkel** | GSFC | Overview on calibrating Landsat-7 and 8 and current and upcoming hyperspectral instruments |
| **Chris Neigh** | GSFC | Hyperion long-term stability at the Libya-4 desert calibration site |
| **Lawrence Ong** | Science Systems and Applications, Inc. (SSAI) | Earth Observing-1 (EO-1) calibration |
| **Steve Ungar** | GSFC | Geo-correction or geo-corruption using various pushbroom systems |

**Table 5. Day 2, Session 2 Technical Presentations:** The Intelligent Payload Module.

| Presenter | Affiliation | Topic |
|---|---|---|
| **Dan Mandl** | GSFC | IPM concept evolution |
| **Vuong Ly** | GSFC | IPM prototype and metrics for data processing components |
| **Steve Chien** | JPL | Generation of Landsat 8 data products onboard EO-1 |
| **Charles Norton** | JPL | CubeSat technology flight validation and the Intelligent Payload Experiment (IPEX) |
| **Steve Chien** | JPL | Flight validation of HyspIRI IPM concepts on IPEX CubeSat |
| **Chris Wilson** | University of Florida | A multifaceted hybrid system for space computing |
| **Vuong Ly** | GSFC | Update on the NASA data cloud |
| **Maria Patterson** | University of Chicago | Cloud-based scanning analytics for hyperspectral data |
| **Molly Brown** | GSFC | Overview of NASA's mFarms (African farmers getting crop-related science data on their cell phones) |
| **Pat Cappelaere** | Vightel | OpenGeoSocial Application Programming Interface (API): product discovery/distribution via social networks |
| **John Evans** | Global Science and Technology, Inc. (GST) | Distributed architecture for satellite observation support of disasters |

**Table 6. Day 3:** HyspIRI Aquatic Study Group Presentations.

| Presenter(s) | Affililation(s) | Topics |
|---|---|---|
| **Kevin Turpie** | UMBC | HASG overview and progress report |
| **Liane Guild** and **Sherry Palacios** | NASA's Ames Research Center | Phytoplankton functional types and coastal water quality |
| **Heidi Dierssen** | University of Connecticut | The Portable Remote Imaging Spectrometer (PRISM) airborne hyperspectral instrument and observations of submerged aquatic vegetation |
| **Bo-Cai Gao** | NRL | Atmospheric correction of satellite images taken over water |

### Day 3

On the final day of the meeting, **Kevin Turpie** [UMBC] hosted a meeting of the HyspIRI Aquatic Study Group (HASG). Presentations during the meeting are summarized in **Table 6**. As an added benefit, **Ray Kokaly** [USGS] facilitated a one-day tutorial on custom processing routines for spectroscopic measurements using ENVI image processing software.

### Summary

The participants presented valuable information on the HyspIRI Mission. A clear conclusion of the meeting was that successful use of HyspIRI data and implementation of an information system and improved technology (such as IPM) will produce a better and more usable set of global-scale products. ■

meeting summaries

# 2014 Landsat Science Team Meeting

*Thomas Loveland, U.S. Geological Survey Earth Resources Observation and Science Center, loveland@usgs.gov*
*Michael Wulder, Canadian Forest Service, Pacific Forestry Centre, Natural Resources Canada, mwulder@nrcan.gc.ca*
*James Irons, NASA's Goddard Space Flight Center, james.r.irons@nasa.gov*

## Introduction

The U.S. Geological Survey (USGS)-NASA Landsat Science Team (LST) met in Corvallis, OR, July 22-24, 2014. The U.S. Forest Service Pacific Northwest Research Station and Oregon State University hosted the meeting. Objectives for the meeting included reviewing the status and operations of Landsat 7 and 8, reporting on the status of programmatic sustainable land imaging, developing concepts and specific actions for making the Landsat archive more relevant to the scientific community, and identifying Landsat products that expand Landsat's usefulness for science and applications. All meeting presentation materials are available at *landsat.usgs.gov/science_LST_July_22_24_2014.php*.

Landsat Science Team members in Corvallis, OR. **Image credit:** Thomas Loveland

The LST co-chairs **Thomas Loveland** [USGS Earth Resources Observation and Science (EROS) Center—*Senior Scientist*] and **Jim Irons** [NASA's Goddard Space Flight Center (GSFC)—*Landsat 8 Project Scientist*], opened the three-day meeting with a review of the maturation of the Landsat program and the increasing advances in Landsat use across a wide range of scientific and operational investigations. Operational natural resources monitoring programs are finding Landsat 8 data to be of superior quality to that of previous Landsat satellites. The 2008 Landsat free data policy has transformed Landsat applications and has stimulated the growth of time-series studies spanning large areas and long temporal periods. As a result, the need for Landsat imagery—and especially new higher-level Landsat products—has grown substantially.

## Landsat Status

**Brian Markham** [GSFC—*Landsat 8 Calibration Scientist*] reported that Landsat 8 radiometric and geometric performance was excellent. Data from the Operational Land Imager (OLI) have signal-to-noise ratios that are two-to-three times better than specifications and up to eight times better than the Landsat 7 instruments. OLI radiometry has been quite stable since launch and the OLI absolute radiance uncertainty requirement of <5% is being met. Image geodetic and geometric accuracies are exceeding requirements and the improved geometric accuracy is better than the locational Ground Control Points (GCP) currently used for orthorectification. As a result, Landsat 8 images will be used to improve the accuracy of the Landsat GCP library.

Regarding the Thermal Infrared Sensor (TIRS), radiometric performance is relatively stable for both thermal channels. Markham reported that there are cross-track artifacts in the thermal bands that appear as ghost signal values. While both bands are affected, with a bias adjustment, band 10 now has errors of 1 K or less. The problem is more evident in band 11; as such, the use of band 11 and split-window surface temperature techniques are not recommended. Stray light has been identified as the cause of the ghosting, and procedures are being evaluated to correct the problem.

**Brian Sauer** [USGS EROS Center—*Landsat Sustaining Engineering Project Manager*] provided an update on Landsat operations and archive status. In particular, he stated that Landsat 7 continues to function well. Solid-state data recorder capacity has declined (currently at 80% of original), but some of the lost storage may be recoverable. The number of daily acquisitions has been increasing and is currently around 440 sunlit scenes per day—well exceeding the design requirement of 250 scenes per day. The projected fuel-based end of mission for Landsat 7 is expected to be in early 2018, so fuel levels are being monitored closely. He noted that operational practices could affect the projected date.

Landsat 8 is also functioning nominally. On a couple of occasions, the spacecraft and systems went into a "safe hold" mode due to performance anomalies occurring

during calibration maneuvers. However, the events had no significant impact on Landsat 8 systems. The USGS is evaluating the acquisition capacity of Landsat 8 during the 2014 growing season. Currently, 725 sunlit scenes are being collected daily—beyond the design requirement of 400. The performance and cost of the expanded acquisition rates will be evaluated at the end of the growing season; a decision will then be made regarding the long-term acquisition plan. **Darrel Williams** [Global Science and Technology, Inc.—*Chief Scientist*] put this into historical context by noting that during the Landsat commercial era (1980s and 1990s), only 50 Landsat scenes were collected each day.

Sauer also reported that the Landsat archive now holds almost 5.3 million images. The archive is growing rapidly due to the success of the Landsat Global Archive Consolidation (LGAC) activity in which more than 3 million historical images—dating back to 1972—have been recovered from International Cooperator (IC) archives around the world; almost all past ICs are cooperating. European holdings are currently being transferred, and plans are underway to receive Landsat holdings from Thailand and possibly India.

Finally, Sauer summarized plans for Landsat product improvements, including:

- Implementation of a new cloud mask algorithm, called *fmask,* developed by Boston University for use with Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and OLI data (early 2015);
- improvement of the Landsat GCP library (beginning in late 2014);
- generation of systematic terrain-corrected ETM+ images when precision ground control corrections cannot be applied (schedule TBD);
- increased Landsat distribution cache capacity (fall 2014);
- generation of scene-based, top-of-atmosphere (TOA) reflectance scaling factors for Landsats 1-7 (winter 2015);
- provision of TOA reflectance enhanced metadata that includes scene-specific, per-pixel, solar azimuth and sensor viewing angle metadata for use in reflectance conversions for Landsats 4-8 (winter 2014);
- production of quality bands for Landsats 1-7 (planning phase initiated);
- correction of TIRS ghosting (TBD); and
- improvement of digital elevation models used for orthorectification (study yet to be initiated).

**John Dwyer** [USGS EROS Center—*Landsat Project Scientist*] provided an update on plans to provide a data quality band for Landsats 1-7, based on the Landsat 8 data quality band. Dwyer also reported that work is underway to provide atmospherically corrected Landsat 8 surface reflectance products by late 2014. These will be consistent with Landsat 4-7 surface reflectance datasets. Research is continuing on surface temperature capabilities. Provisional Landsat 4-7 products should be available by the middle of 2015.

### Sustaining Land Imaging Discussion

NASA and USGS representatives presented their perspectives on efforts to develop a long-term Landsat strategy. **Jim Irons** summarized the public information that has come from the NASA–USGS Architectural Study Team (AST) that is exploring technical options for future Landsats. The AST has evaluated a wide range of technical approaches that will be considered by NASA and Department of the Interior (DOI) leadership. **Tim Newman** [USGS—*Land Remote Sensing Program Coordinator*] and **Sarah Ryker** [USGS—*Acting Associate Director*] described ongoing efforts to better understand Landsat requirements. A DOI priority is avoiding data gaps, and maintaining the current eight-day repeat capabilities afforded by Landsats 7 and 8. They also mentioned that the National Earth Observations Task Force of the Office of Science and Technology Policy just released a strategic plan for Earth observations (*www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/national_plan_for_civil_earth_observations_-_july_2014.pdf*). The plan identified Landsat as one of the highest-impact U.S. observation programs.

### Other Landsat Topics

**Holly Miller** and **Larisa Serbina** [both at USGS' Fort Collins Science Center] presented the results of research on the users, uses, and value of Landsat imagery. Their team recently completed a survey of more than 13,000 Landsat data users. Survey results show that the use of Landsat is growing and that users have greater dependency on Landsat imagery to meet their work responsibilities than ever before. Using a contingent valuation method, they estimated that the 2012 economic value of Landsat data to U.S. users alone was approximately $1.79 billion. They also reviewed a series of Landsat applications associated with water resources as a way to illustrate the growing value of Landsat data. The full report is available at *pubs.usgs.gov/of/2013/1269/pdf/of2013-1269.pdf*.

**Kass Green** [Kass Green & Associates] provided an update on the activities of the Landsat Advisory Group (LAG), a subcommittee of the DOI National Geospatial Advisory Committee. The LAG recently completed reports on future Landsat products, cloud computing, and the National Research Council's

*Landsat and Beyond* study. The LAG is now focused on updating their earlier report on Landsat uses.

**Rick Lawrence** [Montana State University] gave an overview of AmericaView, a university-led consortium composed of consortia from 39 different states (*www.americaview.org*) dedicated to advancing remote sensing education, outreach, and research. Currently, there are nearly 40 AmericaView members, associates, and affiliates. AmericaView supports between 70 and 80 research projects dealing with ecological monitoring, land cover change, agricultural management, wildfire risk assessment, water quality monitoring, and other topics.

### Landsat and Sentinel-2 Collaboration

**Benjamin Koetz** [European Space Agency (ESA)] described the developmental status of ESA's Sentinel-2. This mission will have capabilities similar to Landsat, with 13 multispectral bands, multiresolution imaging over a 290-km (~180-mi) swath at resolutions of 10, 20, and 60 m (~33, 66, and 197 ft, respectively), five-day revisit time with two satellites, and plans to systematically image the global landmass and coasts. Sentinel-2a is scheduled for launch in spring 2015 and the Sentinel-2b launch date is scheduled to take place a year later (spring 2016). The ramp-up to operational status for Sentinel-2 will take approximately one year and the mission will follow a free and open data policy.

**Jeff Masek** [GSFC—*Landsat Project Scientist*] and **John Dwyer** discussed U.S. efforts to archive and distribute Sentinel-2 imagery, and improve synergy between Sentinel-2 and Landsat. Masek reported on efforts between NASA and ESA to evaluate Landsat 8 OLI and Sentinel-2 Multi-Spectral Instrument (MSI) sensor characteristics in order to advance the interoperability of data from the two missions prior to launch. In addition, NASA is funding research to look at several Landsat/Sentinel-2 topics, including harmonized surface reflectance and other higher-level science products, as well as common gridding approaches. Dwyer summarized USGS plans to redistribute Sentinel-2 projects. At a minimum, the USGS will provide access to orthorectified, TOA reflectance (Level 1C) products in ESA's standard 100 x 100-km (~62 x 62-mi) tiles. The USGS is also evaluating higher tiers of service that would enable more direct integration of Sentinel-2 products with those from Landsat.

### Landsat Science Presentations

LST member and meeting host, **Warren Cohen** [U.S. Forest Service Pacific Northwest Research Station] organized a series of presentations by his research team from the Laboratory for Applications of Remote Sensing in Ecology (LARSE). A centerpiece of LARSE research is a national interagency effort to establish a Land Change Monitoring System (LCMS) based on Landsat. Cohen featured three projects, including an investigation using Landsat data from 1972 to the present to identify the remaining original, native forests in Haiti; a study of the causes and consequences of increased insect and disease activity in the Western U.S. (with **Justin Braaten** [Oregon State University (OSU)]); and a study characterizing forest stress and vulnerability in the Pacific Northwest using Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat (with **David Mildrexler** [OSU]).

The LST members then gave brief highlights of their recent Landsat research, which are presented in **Table 1**.

**Table 1**. Presentation highlights from LST members.

| Presenter(s) | Affiliation(s) | Highlight |
|---|---|---|
| Martha Anderson | U.S. Department of Agriculture's Agricultural Research Service | Landsat, MODIS, and Geostationary Operational Environmental Satellite data are being successfully integrated to estimate daily water use at field scale. |
| David Johnson | USGS National Agricultural Statistical Service | Landsat 8 could finally make it practical to have operational cropland monitoring in developing countries. |
| John Schott | Rochester Institute of Technology | Research is proceeding that should result in Landsat surface temperature products, first for North America, but eventually globally. |
| Valerie Thomas and Randy Wynne | Virginia Tech | Landsat 8 research is addressing leaf area estimation, accounting for cirrus clouds in land cover classification, and monitoring forest change. |
| Joel McCorkel | GSFC | Landsat 8 OLI data intercomparisons were made with aerial and *in situ* radiometric measurements. |
| Curtis Woodcock | Boston University | Image classifications made using Landsat 8 are superior to results obtained from Landsat 7. |

**Table 1. (cont.)** Presentation highlights from LST members.

| Presenter(s) | Affiliation(s) | Highlight |
|---|---|---|
| Ted Scambos | University of Colorado | Landsat 8 data are showing good results in characterizing a range of snow and ice phenomena including ice flow tracking, melt lake depth, and thermal mapping of the Antarctic interior. |
| Robert Kennedy | Boston University | Time-series analysis in a cloud-based computing environment is investigated. |
| David Roy | South Dakota State University | Progress is being made in creating seamless temporal composites for the U.S. using Landsat 8 and for the globe using Landsat 5 and 7. |
| Eric Vermote | GSFC | Landsat 8 surface reflectance processing algorithms were developed and tested with positive results. |
| Rick Allen<br>Ayse Kilic | University of Idaho<br>University of Nebraska | Analyses were carried out to determine specifications for thermal imaging on Landsat 9 and beyond. |
| Mike Wulder | Canadian Forest Service | Canada's contemporary forest history is being recreated using Landsat time-series data. |
| Alan Belward | European Commission Joint Research Centre | A Sentinel-2 global surface water monitoring strategy was prototyped using Landsat data. |
| Yongwei Sheng | University of California, Los Angeles | Substantial progress has been made mapping lakes across the globe using Landsat data. |

**Future Landsat Science Products**

The final topic of the meeting involved requirements and specifications for higher-level Landsat science products, led by **David Roy** [South Dakota State University] and **Curtis Woodcock** [Boston University], co-leaders of the LST. As a general philosophy, the LST recognized three levels of Landsat products:

1. **Level 1T (L1T)**: The basic Landsat product that is essential for remote sensing methods research and scientific investigations in which there is a need to control processing steps.
2. **Analysis Ready Data**: Seamless (mosaiced) data that include individual cloud-free pixels as well as pixel-based layers processed to higher levels of temporal aggregations and that have advanced corrections applied. All Landsat archive scenes are included.
3. **Derived Landsat Science Products**: Geospatial datasets and statistical summaries describing geophysical properties, biophysical conditions, and land cover characteristics and dynamics.

The LST also emphasized the importance of considering broad community requirements, transparency in planning and evaluating Landsat product concepts (e.g., including the development of Algorithm Theoretical Basis Documents), the use of peer-reviewed methods, and adherence to definitions and standards identified by national and international science forums. The team also stressed that products need to be generated from the full Landsat archive, including the Multispectral Scanner (MSS). However, they also recognize the need to phase development by instrument groups (e.g., MSS, TM, ETM+, and OLI).

Regarding future L1T improvements, LST recommendations included:

- Improving the technical depth and quality of L1T documentation;
- making the 30-m (~98-ft) Digital Elevation Model used for Landsat terrain corrections available;
- improving the use of the Landsat 8 cirrus band in cloud and shadow masking;
- producing spatially explicit cloud and shadow masks for Landsats 1-7; and
- extending metadata content to facilitate derivation of solar and viewing geometry for Landsats 1-7.

The LST also recommended that greater attention be given to Landsat L1T versioning so that users are aware of the date, level, and specific parameters (e.g., Calibration Parameter Files) associated with the data they are currently using.

Regarding analysis-ready Landsat data, this is an area where more discussion is needed before a

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consensus can be reached. Basic properties of analysis-ready data include:

- Immediate access to the full Landsat archive (vs. on-demand processing);
- access to individual-pixel observations and seasonal composites;
- surface reflectance and temperature measurements;
- cloud and shadow detection and masking;
- bidirectional reflectance distribution function (BRDF) normalization;
- gridded composites; and
- robust data-delivery services.

With analysis-ready data, consistency and traceability are critical. As Landsat data are increasingly used for long-term climate studies, establishing collections in which the entire Landsat archive is processed using consistent, traceable, and peer-reviewed procedures was encouraged.

The discussion of higher-level Landsat science products was limited due to time constraints; exploration of this topic will be continued in future meetings. Generally, the team suggested that—based on the Landsat mission goal of global land change monitoring—emphasis should be given to land-change science products. It is important that the definitions used for MODIS products and those used for the Suomi National Polar-orbiting Partnership satellite's Visible Infrared Imaging Radiometer Suite products remain consistent, and that all products adhere to international standards. Attention must also be paid to both categorical and quantitative land cover and condition measures.

The final topic of discussion was the relationship between Landsat and Sentinel-2 datasets. In order to benefit from the synergy associated with the two similar multispectral missions, the LST recommended that, at a minimum, USGS should be archiving and distributing Sentinel-2 L1C data. Beyond that, the LST encouraged development of processing techniques that allow interoperability. In addition, they encouraged research that addresses different BRDF effects, efforts to ensure consistency in surface reflectance products, and work on understanding and correction of spectral bandwidth differences. Some of these issues are already being addressed by NASA-sponsored research.

The next meeting is tentatively set for February 3-5, 2015; at GSFC in Greenbelt, MD. ■

announcements

## Come Explore NASA Science at the 2014 Fall AGU Meeting

Please plan to visit the NASA booth (# 2335) during the American Geophysical Union's (AGU) forty-seventh annual Fall Meeting! This year's exhibit hall will open on Monday, December 15, and will continue through Friday, December 19.

Throughout the week representatives from several different programs and missions are scheduled to give dynamic Hyperwall and Keynote presentations. Presentations will cover a diverse range of research topics, science disciplines, and programs within NASA's Science Mission Directorate, including Earth Science, Planetary Science, Astrophysics, and Heliophysics.

At the booth there will also be a wide range of other science presentations, demonstrations, printed material, and tutorials on various data tools and services.

A daily agenda will be posted on the Earth Observing System Project Science Office website—*eospso.nasa.gov*—in early- to mid-December.

We hope to see you in San Francisco!


A NASA Science presentation using the dynamic Hyperwall display during the 2012 AGU Meeting. **Image credit:** NASA

# Summary of the Precipitation Measurement Mission Science Team Meeting

*Ellen Gray, NASA's Goddard Space Flight Center, ellen.t.gray@nasa.gov*

**Introduction**

The Precipitation Measurement Mission's (PMM) Science Team meeting took place in Baltimore, MD, August 4-7, 2014. The PMM program supports scientific research, algorithm development, and ground-based validation activities for the Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Measurement (GPM) Core Observatory that launched on February 27, 2014.

The PMM Science Team meeting opened with a special memorial session dedicated to **Arthur Hou**, the former GPM Project Scientist, who passed away November 20, 2013. Hou's friends and colleagues remembered him as an exceptional scientist and leader who was able to build and navigate the international relationships that got the GPM mission off the ground—see *A Tribute to the "Heart and Soul" of the GPM Mission* on page 32.

The TRMM and GPM missions are co-led by NASA and the Japan Aerospace Exploration Agency (JAXA), with numerous additional international partners. The international community was well represented at the meeting, with more than 190 attendees from 14 countries, in addition to representatives from NASA, JAXA, the National Oceanic and Atmospheric Administration (NOAA), universities, and other partner agencies. Among the topics discussed—in 13 sessions of presentations and 2 poster sessions—were status updates from the TRMM and GPM programs, international activities, algorithm development, and ground validation, as well as science reports from team members.

**Programmatic Updates and TRMM and GPM Status Reports**

**Mike Freilich** [NASA Headquarters (HQ)—*Director of the Earth Science Division*] and **Ramesh Kakar** [HQ—*GPM Program Manager*] discussed the current state of NASA Earth Science missions and the immediate budget outlook for the next year, which is steady. The current PMM Science Team is in its second year of activities; in the coming months a solicitation for the ninth science team will go out—with proposals due in June 2015.

**Scott Braun** [NASA's Goddard Space Flight Center (GSFC)—*TRMM Project Scientist*] provided an update on TRMM. The biggest news is that TRMM is out of station-keeping fuel. The last drag-reduction maneuver to maintain TRMM's altitude was on July 8, 2014, and the decision was made to let the instruments continue to collect data at a reduced capacity as the spacecraft slowly loses altitude over the next 18 to 20 months. Science data from the TRMM Microwave Imager (TMI) will be collected until the spacecraft is shut down, which is estimated to be in April of 2015. The Precipitation Radar (PR) can only collect good science data at two altitudes, its current 407 kilometers and its original altitude of 350 kilometers.

**Nobuhiro Takahashi** [National Institute of Information and Communications Technology, Japan] explained JAXA's plan to collect data as TRMM passes through these altitudes, but at other altitudes they will stop science data collection and conduct experimental observations. During TRMM's remaining time in orbit, it will be part of the GPM constellation.

**Gail Skofronick-Jackson** [GSFC—*GPM Project Scientist*] and **Art Azarbarzin** [GSFC—*GPM Project Manager*] discussed the current status of the GPM Core Observatory. The satellite has a mission lifetime of 3 years, but its fuel unexpectedly appears to be sufficient for 13 to 15 years—an estimate that includes enough for a controlled reentry. The satellite is returning excellent data, but Skofronick–Jackson did note a couple of issues. The GPM Microwave Imager (GMI) experiences radio frequency interference in two channels due to reflection of satellite–broadcast TV signals from frozen lakes, and from certain wireless motion detectors when installed in sufficiently large numbers. Also, there have been some unexpected magnetic effects on the GMI—which are thought to be due to Earth's magnetic field but do not impact the instrument's performance—that have been corrected with an algorithm update. Neither issue is expected to significantly impact science operations, but both will be monitored.

**Erich Stocker** [GSFC] discussed the status of the GPM data products. GPM Core and constellation data products are scheduled to be publicly released on September 2, 2014[1]. Products range from near-real-time data from individual sensors and orbits to the Integrated Multi-satellite Retrievals for GPM (IMERG) product that will combine data from GPM with partner satellite data, which will be released in December 2014. The Precipitation Processing System at Goddard is meeting its latency requirements for the datasets.

**Dalia Kirschbaum** [GSFC—*GPM Applications Scientist*] discussed GPM applications and outreach activities, showing the new, user-friendly web interface for downloading data (*pmm.nasa.gov/data-access/downloads/gpm*).

[1] **Editors Note**: This release took place as scheduled on September 2. See the announcement in the September–October 2014 issue of *The Earth Observer* [**Volume 26, Issue 5**, p. 19].

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**Riko Oki** [JAXA—*GPM Project Scientist*] and **Kinji Furukawa** [JAXA—*GPM Project Team Leader*] gave an overview of JAXA's activities and the checkout of the Dual-Frequency Precipitation Radar (DPR), whose initial results—when compared to the TRMM PR—are good. Of note, the DPR does have more *side-lobe clutter* (which causes noise on either side of the swath) than the TRMM PR, but software fixes have been applied. **Yukari Takayabu** [University of Tokyo] described the preliminary results of the increased sensitivity of the DPR's two bands as very good and promising for the study of cloud microphysics. **Toshio Iguchi** [JAXA] gave an update on JAXA's DPR algorithms and the major differences from those for the TRMM PR.

**Algorithm Status**

**Chris Kummerow** [Colorado State University], **Bob Meneghini** [GSFC], **Bill Olsen** [University of Maryland, Baltimore County], **George Huffman** [GSFC], and **Tom Wilheit** [Texas A&M University] each gave presentations on algorithm status for GMI, DPR, combined GMI and DPR, IMERG combined global data product, and constellation partner datasets, respectively. A few minor glitches notwithstanding, development of all the algorithms is progressing well, and all are on schedule for the September 2 data release (now released), with the exception of IMERG, which is planned for a December 2014 release.

**Ground Validation**

**Walt Petersen** [NASA's Wallops Flight Facility] summarized GPM's ground validation efforts, including the two campaigns that took place since the last PMM Meeting: The Iowa Flood Studies (IFloodS), which took place in northeastern Iowa in 2013[2], and the Integrated Precipitation and Hydrology Experiment (IPHEx), which took place in North Carolina in the summer of 2014.

**Withold Krajewski** [University of Iowa—*IFloodS Principal Investigator*] described IFloodS in more detail. GPM partnered with the Soil Moisture Active Passive (SMAP) mission for this campaign, which examined conditions that lead to flooding; they have done preliminary analysis of the hydrology.

**Ana Barros** [Duke University—*IPHEx Principal Investigator*] described the IPHEx field campaign, which looked at precipitation over the Appalachian mountain region, and has just wrapped up its intensive observing period.

**Lynn McMurdie** [University of Washington] described plans for the next GPM ground validation campaign, the Olympic Mountain Experiment (OLYMPEX), which will take place on the Olympic Peninsula in Washington in the fall and winter of 2015-16.

**Giullia Panegrossi** [CNR–ISAC[3], Italy] reported on ground validation of GMI algorithms in European experiments that serve as an independent validation for rainfall, snowfall, and related hydrology estimates. Similarly, **Pierre Kirstetter** [National Severe Storms Laboratory (NSSL), University of Oklahoma] showed results of comparing data from NOAA's NEXRAD multiradar and multisensor networks to GPM and TRMM rainfall estimates. This work better characterizes differences between sensors in order to achieve more consistent datasets from multiple sensors that can be used to complement the ground validation campaigns. Kirstetter also discussed other ground validation experiments conducted by GPM's international partners.

**Science and Applications**

Three themes emerged among the science reports: evaluation and improved approaches to GPM algorithm retrievals of rain and snow, studies of the precipitation processes that improve parameterization for GPM algorithms, and longer-term global studies of convection and rain rates using TRMM's 16-year record. The **Table** on page 31 gives a list of speakers and presentations.

One of the new capabilities provided by GPM is its ability to detect and estimate snowfall. The processes governing the formation of snow are somewhat more complicated than those for rain, since there are many possible ways for snow to form, grow, and/or melt inside clouds. A number of presentations discussed approaches using measurements from dual-frequency radar on the ground and comparing them to those obtained from DPR to help distinguish between different snow processes. In particular, data from past snow ground validation field campaigns are being used to study these processes: **David Hudak** [Environment Canada] is evaluating differences in synoptic *versus* lake effect snow; **Dmitri Moisseev** [University of Helsinki] is working with data from multiple sites in Finland; and **Brian Colle** [Stony Brook University] is looking at microphysical processes of snow formation to improve the parameters used in models to represent snowfall.

**Ralph Ferraro** [NOAA—*Chief for the Satellite Climate Studies Branch*] discussed NOAA's efforts to assimilate GPM data into operational models. NOAA is using GPM data for hurricane, flood, and hydrology applications. **Peter Lean** [European Centre for Medium-Range Weather Forecasting (ECMWF)] discussed incorporating GPM data into weather forecasts in European models. Initializing models with data from GMI has improved model data for both groups, such that they better fit with observations.

[2] To learn more, read "A Flood—of Information—Is Needed" the January–February 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 1,** pp. 12-18].

[3] CNR-ISAC stands for the Institute of Atmospheric Sciences and Climate of the Italian National Research Council, *Istituto di Scienze dell'Atmosfera e del Clima*.

**Table**. Science and Applications Presentations Given During the PMM Science Team Meeting.

| Presenter | Affiliation | Title* |
|---|---|---|
| Christopher Ruf | University of Michigan | Time and space sampling coordination between PMM and CYGNSS ocean surface winds |
| Jonathan Gourley | NOAA | Use of NSSL ground radar datasets to support IPHEx and GPM |
| Marshall Shepherd | University of Georgia | Urban-snow relationships: Process studies and a new framework for optimizing and managing global urban water systems in the GPM era |
| Efi Foufoula-Georgiou | University of Minnesota | A new algorithm for GPM passive microwave rainfall retrieval: Extremes, discontinuities, and spatial structure |
| Milija Zupanski | Colorado State University | Improvements of the WRF-EDAS for assimilation and downscaling of the GPM satellite precipitation information |
| Luca Baldini | CNR-ISAC | Scanning strategies For Tier 1 GPM ground validation radars |
| Jinho Shin | Korea Meteorological Administration | GPM ground validation system optimization and operation over the Korean Peninsula |
| Stephen Durden | NASA/JPL | Global surface characteristics using GPM |
| Mircea Grecu | GESTAR NASA | Expectation maximation analysis of the consistency of GPM combined retrievals |
| Wesley Berg | Colorado State University | How calibration and sensor differences impact precipitation estimates from the GPM radiometer constellation |
| Robert Adler | University of Maryland | TRMM/GPM climatology and variations during the TRMM era and earlier |
| Daniel Cecil | MSFC | Extremely low brightness temperatures with deep convection—discriminating signal from noise |
| Edward Zipser | University of Utah | Latent heating profiles and their relationship to the structure and intensity of convective systems |
| Christa Peters-Lidard | GSFC | Dynamic emissivity estimation with calibrated and simplified forward models |
| Anthony Del Genio | GISS | Sensitivity of MJO hindcasts to cumulus parameterization assumptions |
| Robert Houze | University of Washington | Extreme convection in the Equatorial Zone as seen by 16 years of TRMM Precipitation Radar observations |
| Anthony Illingworth | University of Reading | Chilbolton radar |
| Alexis Berne | EPFL-LTE | Radar and disdrometer measurements: Processing and evaluation using HyMeX data |
| Mekonnen Gebremichael | University of Connecticut | Validation of satellite rainfall products across the Blue Nile basin |
| Daniel Vila | CPTEC/INPE | GoAMAZON - CHUVA - The last field campaign |
| Cliff Mass | University of Washington | High-resolution modeling support of Olympex |
| Carl Schreck | NCSU/CICS-NC | A global survey of Kelvin waves and tropical cyclogenesis |
| Anita Rapp | Texas A&M University | Relationships between properties of subtropical cumulus convection and lower tropospheric water vapor |
| Eugenia Kalnay | University of Maryland | Effective assimilation of TMPA observations |
| Liang Liao | Morgan State University | Uncertainties of GPM/DPR rain estimates caused by DSD parameterizations |

* **List of acronyms used in Table *not* found in text**: CYGNSS = Cyclone Global Navigation Satellite System; WRF-EDAS = Weather Resarch and Forecasting–Environmental Data Assimilation System; MJO = Madden–Julian Oscillation; HyMeX = Hydrological Cycle in the Mediterranean Experiment; CHUVA = *Cloud processes of the main precipitation systems in Brazil* (English translation of Brazilian acronym); TMPA = TRMM Multisatellite Precipitation Analysis; DSD= Drop Size Distribution.

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***A Tribute to the "Heart and Soul" of the GPM Mission***

On August 4, 2014, a memorial symposium took place to honor the life and work of **Arthur Hou**, former Project Scientist of the GPM Mission, who passed away on November 20, 2013, three months shy of GPM's launch. The memorial event took place at the Embassy Suites–Grand Historic Venue in Baltimore, MD, in conjunction with the PMM Science Team Meeting.

**Ramesh Kakar** gave the opening remarks; he remembered Arthur as the "heart and soul of the GPM mission," and gave him credit for getting the mission back on track at a time when it was foundering. **Michael Freilich** also gave some remarks on Arthur's central role to the mission, saying that, "Without Arthur's effort with GPM, we would be worse off as a nation and worse off as a species." **Piers Sellers** [GSFC—*Deputy Director of Science and Exploration Directorate*] described Arthur as "master conductor" who will be remembered with great affection.

Many speakers at the symposium shared anecdotes from Arthur's distinguished professional career—see full agenda for more. For example, **Isaac Held** [NOAA] knew Arthur as a graduate student at Harvard, where he began work on theories of large-scale systems in the atmosphere, in particular what controls the size, strength, and transport of air masses in the Hadley Cell. **Bob Adler** [UMD] knew Arthur as a colleague; the two worked together when Arthur came to NASA in 1990 and worked on the TRMM mission; he said that Arthur's research influenced how data were assimilated into models. He recalls that Arthur didn't like how Adler's multisatellite flood monitoring approach was done, and wanted to build them better tools to bridge observations and models.

A recurring theme during the symposium was Arthur's ability to bring people together. **Ed Zipser** [University of Utah] spoke of Arthur as a champion of the GPM mission, who really understood how to deal with people. That charisma was most helpful in bringing together the international community to support his vision of combining international satellites to produce a robust worldwide precipitation dataset. **Vincenzon Levizzani** [ISAC] remembers Arthur as emphatically inclusive in his interactions with international partners. Arthur spent hours of negotiating in meetings and on telephone calls across both the Pacific and the Atlantic Oceans, working through armies of lawyers and bulky governmental offices to help make the GPM concept a reality.

> I really hope that Arthur is remembered every time a piece of data from GPM helps to further our understanding of precipitation, helps to predict the direction of the next hurricane, flood prediction, or landslide. Every time we save a life, I hope that some scientist out there remembers Arthur and that his legacy for this mission lives on.
>
> —**Gail Skofronick-Jackson** [GSFC—*GPM Project Scientist*].

There were also glimpses into Arthur's personal life shared during the symposium. Levizanni also remembered Arthur as a "man of culture and science, a citizen of the world." Their friendship was cemented over a shared love of the opera. **James Carton** [UMD] knew Arthur when he was a post-doc, and says they got to know each other better on a sailing trip. Arthur was an enthusiastic sailor throughout his life. It was on one such trip that he met his wife **Sandra**. Both Sandra and their daughter **Sara** both spoke at the symposium, remembering their husband, father, and best friend.

Though Arthur died a few months short of seeing his satellite finally reach space, his legacy lives on through the pioneering research enabled by GPM. With an improved global picture of rain and falling snow, scientists and others can gain a better understanding of Earth's climate, regional effects of severe storms, and impacts on water resources for society.

**Closing**

**Ramesh Kakar**, **Gail Skofronick-Jackson**, and **Scott Braun** closed the meeting, extending congratulations and thanks to the science team for all their hard work making sure all the algorithms were in place for day one of observations, and their continued work evaluating and improving the new—and in some cases, unprecedented—data as the team enters the GPM era. ■

# Summary of the 2014 Advanced Microwave Scanning Radiometer (AMSR) Science Team Meeting

*Elena Lobl, University of Alabama in Huntsville, Earth System Science Laboratory, lobl@nsstc.uah.edu*

**Introduction**

The Advanced Microwave Scanning Radiometer (AMSR) Science Team meeting took place September 23-24, 2014, in Huntsville, AL. The meeting included presentations related to both AMSR for NASA's Earth Observing System (AMSR-E), onboard Aqua, and AMSR2 onboard the Japan Aerospace Exploration Agency's Global Change Observation Mission – Water (GCOM-W1). There were presentations on the status of the Team Leader Science Computing Facility (TLSCF), the Science Investigator-led Processing System (SIPS), and the archiving facility at the National Snow and Ice Data Center (NSIDC). The science presentations largely described the final algorithms for AMSR-E and new algorithms for AMSR2. Slides and notes from all presentations are available at the NASA AMSR-E website at *wwwghcc.msfc.nasa.gov/AMSR/meetings_2014.html*.

**Day One**

The first day of the meeting consisted of a series of programmatic presentations, followed by several science presentations.

*Programmatic Presentations*

After an introduction by **Roy Spencer** [University of Alabama in Huntsville (UAH)—*AMSR-E Science Team Leader*], **Ramesh Kakar** [NASA Headquarters—*Aqua Program Manager*] described the status of the Aqua spacecraft and the great successes of the Global Precipitation Mission (GPM) Core Observatory launch and early results. Kakar concluded by showing the NASA Earth Science Fleet as it is today; the Decadal Survey Venture Line, including the first selected Earth Venture project called Cyclone Global Navigation Satellite System (CYGNSS)[1]; and a short review of NASA's hurricane field experiments.

**Karen Michael** [NASA's Goddard Space Flight Center (GSFC), Earth Science Data and Information System (ESDIS)—*System Manager*] talked about key ESDIS metrics, *reverb*—a new web-based client for discovering and ordering cross-discipline data from all of Earth Observing System (EOS) Clearing House (ECHO) metadata holdings—Land Atmosphere Near-real time Capability for EOS (LANCE)[2], and two ESDIS data discovery capabilities: Worldview and Global Imagery Browse Services (GIBS).

**Angie Kelly** [GSFC—*EOS Science Interface Manager* and *Constellation Mission Operations Manager*] provided an update on Aqua's status and that of the Afternoon Constellation, or A-Train, of which Aqua is a part. She also mentioned the upcoming 2015 Senior Review and the Third International A-Train Symposium, scheduled for March 4-6, 2015. Kelly also mentioned that Aqua (and other spacecraft in the A-Train) have had quite a few close approaches with space debris that the mission operations team has had to deal with for the past year.

**Dawn Conway** [UAH—Lead software engineer *at AMSR-E's TLSCF*] described the status of the AMSR-E algorithms that are ready for final reprocessing. For the benefit of newcomers to the project, she described TLSCF algorithm delivery and update procedures. She concluded by presenting both AMSR-E and AMSR2 schedules.

**Helen Conover** [UAH, Information Technology and Systems Center (ITSC)—*Manager of the Science-led Investigator Processing System at the Global Hydrology and Climate Center (SIPS-GHCC)*] described the status of the AMSR-E SIPS, AMSR-E products already reprocessed, and the plan for AMSR2 processing. Conover also presented SIPS plans for providing AMSR2 LANCE products.

**Amanda Leon** [NSIDC—*AMSR-E Leader*] presented metrics describing the distribution of archived AMSR-E Science and Validation data. She also had a listing of AMSR-E derived products, amongst which are coregistered AMSR-E, Quick Scatterometer (QuikSCAT), and World Meteorological Organization (WMO) data, daily global land surface parameters, enhanced-resolution Special Sensor Microwave Imager (SSM/I) and AMSR-E daily polar brightness, AMSR-E/Aqua monthly global microwave land surface emissivity, and MEaSUREs'[3] Global Record of daily landscape freeze/thaw status. NSIDC added a new data quality tab to their AMSR-E webpage (*nsidc.org/data/amsre*), following relevant discussion at the 2013 Senior Review. This new tab allows users to find quality assessment files, quality flags, and a data uncertainty report for each standard product. **Brian Krupp** (GSFC/ESDIS) followed Leon, presenting metrics for AMSR-E data distribution to end users.

[1] To learn more please see "NASA Intensifies Hurricane Studies with CYGNSS" in the May–June 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 3**, pp. 12-21].

[2] Read about the latest LANCE User Working Group meeting on page 37 of this issue.

[3] MEaSUREs stands for Making Earth System Data Records for Use in Research Environments *earthdata.nasa.gov/our-community/community-data-system-programs/measures-projects*.

**Masato Yamanashi** [JAXA] presented the status of the AMSR2 instrument flying onboard GCOM-W1 in the A-Train, in front of the Aqua spacecraft. Yamanashi said that GCOM-W1 is "stable and healthy." The AMSR2 has some issues, but they do not impact the observations. The brightness temperatures are being recalibrated, and the new versions will be released to the public in March 2015. The next AMSR2 workshop will be held in Tokyo, Japan, January 14-16, 2015.

**Toshi Takeshima,** [JAXA, Mission Operations System Office] reviewed the status of AMSR-E. He stated that the instrument is rotating at 2 rpm and is very stable, and that JAXA would like to continue this operation indefinitely. In order to avoid saturation of the 89-GHz B channel, JAXA proposes to do a gain adjustment before the end of the year.

*Science Presentations*

**Chris Kummerow** [Colorado State University (CSU)] discussed the latest changes to the Goddard PROFiling algorithm (GPROF). This is the standard algorithm for AMSR2 rainfall over land and ocean, columnar water vapor, total precipitable water (TPW), and wind speed over the ocean only. This new algorithm—GPROF2014—is a truly Bayesian Inversion algorithm. It has 14 surface classes with each surface type having its own database binned by surface temperature and TPW. The database will be finalized after a year of GPM radar/radiometer operations—possibly around mid-April 2015.

**Richard Kelly** [University of Waterloo, Ontario, Canada, Interdisciplinary Centre on Climate Change] presented the "new" approach to developing an AMSR2 algorithm for JAXA. The first essential variable in this approach is snow detection (i.e., to distinguish areas with snow from those with no snow). Kelly uses forest attenuation and atmospheric attenuation corrections and believes that his results for snowcover mapping are robust. Once this mapping is defined, Kelly uses the Dense Media Radiative Transfer – Multi Layers (DMRT-ML) model developed at the French Laboratoire de Glaciologie at Géophysique de l'Environnement (LGGE), to calculate the Snow Water Equivalent (SWE) and snow depth.

**Hiroyuki Tsutsui** [JAXA, Earth Observation Research Center] has examined AMSR2 snow product validation, specifically over the Tibetan Plateau. When compared with Moderate Resolution Imaging Spectroradiometer (MODIS) data and ground-based observations, the AMSR2 products were overestimating both snowcover and SWE. Tsutsui suggested that corrections are needed for the presence of vegetation, the state of the ground (i.e., distinguishing frozen and non-frozen areas), and forest density.

**Marty Brewer** [Remote Sensing Systems] addressed several topics, including detecting 6.9 GHz ocean-reflected radio frequency interference (RFI), detecting and mitigating 10.65-GHz RFI, wind speed through heavy rain, and intercalibration of AMSR2 with AMSR-E using data from the U.S. Naval Research Lab's WindSat spacecraft as a bridge.

The remainder of the first day of the meeting was devoted to a discussion of AMSR2 *ancillary files*—data used in the algorithms from sources other than AMSR2. The U.S. AMSR2 Science Team is trying to develop a shared approach to these commonly used files. Currently, different algorithms use separate files that include only the parameters they need. **David Duncan** [CSU] provided some context for this issue by looking at all the ancillary files used by the AMSR2 algorithm developers. For example, the precipitation algorithm uses Reynolds sea surface temperature (SST) and sea ice flags, while the sea ice algorithm uses SST climatology and brightness temperature ($T_b$) thresholds to determine the possible presence of sea ice. The problem is that under the present approach, i.e., using separate ancillary files, there could be pixels that neither discipline is retrieving—or both are retrieving. By going to a single homogeneous ancillary file that all algorithms could use, this issue would be resolved.

**Danny Braswell** [UAH] followed with a presentation on *cluster analysis,* using two days of AMSR-E brightness temperatures. By using this analysis, all pixels are accounted for in the AMSR2 algorithms. The results of the analysis looked promising.

**Day Two**

The second day began with a series of presentations from the soil moisture algorithm team, followed by two presentations related to sea ice algorithm development.

*Presentations from the Soil Moisture Algorithm Team*

**Eni Njoku** [NASA/Jet Propulsion Laboratory (JPL)] presented an overview of the new AMSR-E/AMSR2 soil moisture algorithm. This new algorithm will be a combination of the Normalized Polarization Difference (NPD) algorithm, developed by JPL, and the Single Channel Algorithm (SCA), developed by the Hydrology and Remote Sensing Laboratory (HRSL), part of the U.S. Department of Agriculture (USDA)'s Agricultural Research Service (ARS).

**Steven Chan** [JPL] presented a flowchart that illustrated the new combined NPD algorithm described earlier by Njoku. The ingest of input data and quality assurance checks are done before the two algorithms separately calculate the soil moisture. The end product, grid-based soil moisture, will be one file containing both results.

**Mariko Burgin** [JPL] talked about the physics of the NPD algorithm, and **Iliana Mladenova** [HRSL/USDA] presented an overview of the SCA. Mladenova also showed an intercomparison between AMSR-E and AMSR2 volumetric soil moisture (VSM); the maps show similar spatial structure. When she did a regional study of this intercomparison, AMSR2 products showed some differences, which will probably disappear once JAXA recalibrates AMSR2 brightness temperatures.

**Jinyang Du** [Numerical Terradynamic Simulation Group and Flathead Lake Biological Station, Division of Biological Sciences, University of Montana (UMT)] is part of a team developing a consistent long-term global land parameter data record using AMSR-E, AMSR2, and MicroWave Radiation Imager (MWRI), flying on the Chinese polar-orbiting meteorological satellite FengYun-3B (FY-3B). Du showed biases in the data and their correction. The UMT team plans to continue this work and to extend the global land parameter. Their data are archived at *nsidc.org/data/nsidc-0451* and *freezethaw.ntsg.umt.edu*.

*Presentations on Sea Ice Algorithms*

**Walt Meier** [GSFC] showed intercalibration analyses he has done with the NASA Team 2 (NT2) algorithm with AMSR-E and AMSR2 data. The ice motion (drift) algorithm that had been used thus far will be replaced with a new algorithm from the University of Colorado. This switch is necessary since the old algorithm can no longer be supported in the event of anomalies.

**Joey Comiso** [GSFC] showed that the NT2, his Bootstrap algorithm, and the European Climate Change Initiative (CCI) Sea Ice algorithm show similar sea ice cover, but with significant differences in the magnitude of the ice concentration. Future issues that Comiso will explore to try to resolve some of the existing discrepancies include looking at the impact of meltponding, land contamination, and the emissivity of new ice.

Both Meier and Comiso showed Arctic and Antarctic ice status—see **Figures 1 and 2,** respectively—during their presentations.

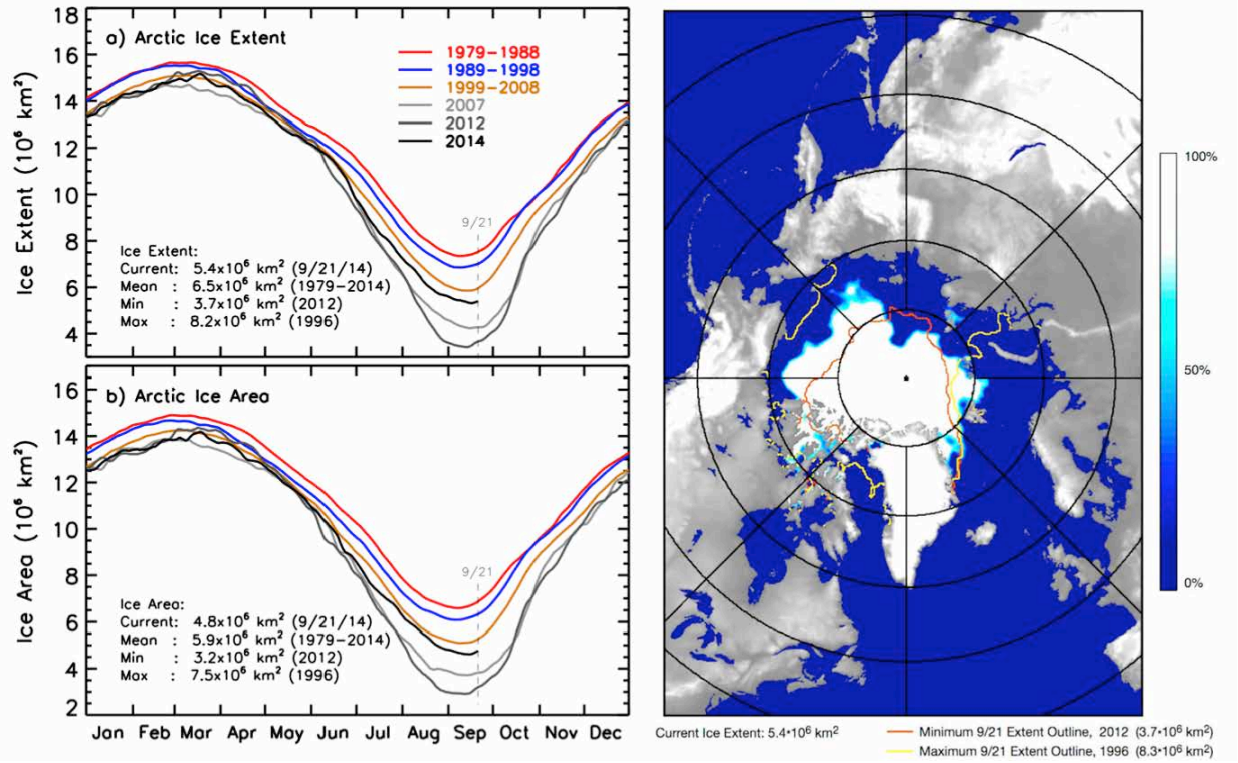


**Figure 1.** The current Arctic sea ice extent is 5.4 x $10^6$ $km^2$ (~2.1 x $10^6$ $mi^2$), approximately half-way between the minimum extent in 2012 [3.7 x $10^6$ $km^2$ (~1.4 x $10^6$ $mi^2$)], and the maximum that occurred in 1996 for the same date [8.2 x $10^6$ $km^2$ (~3.2 x $10^6$ $mi^2$)].

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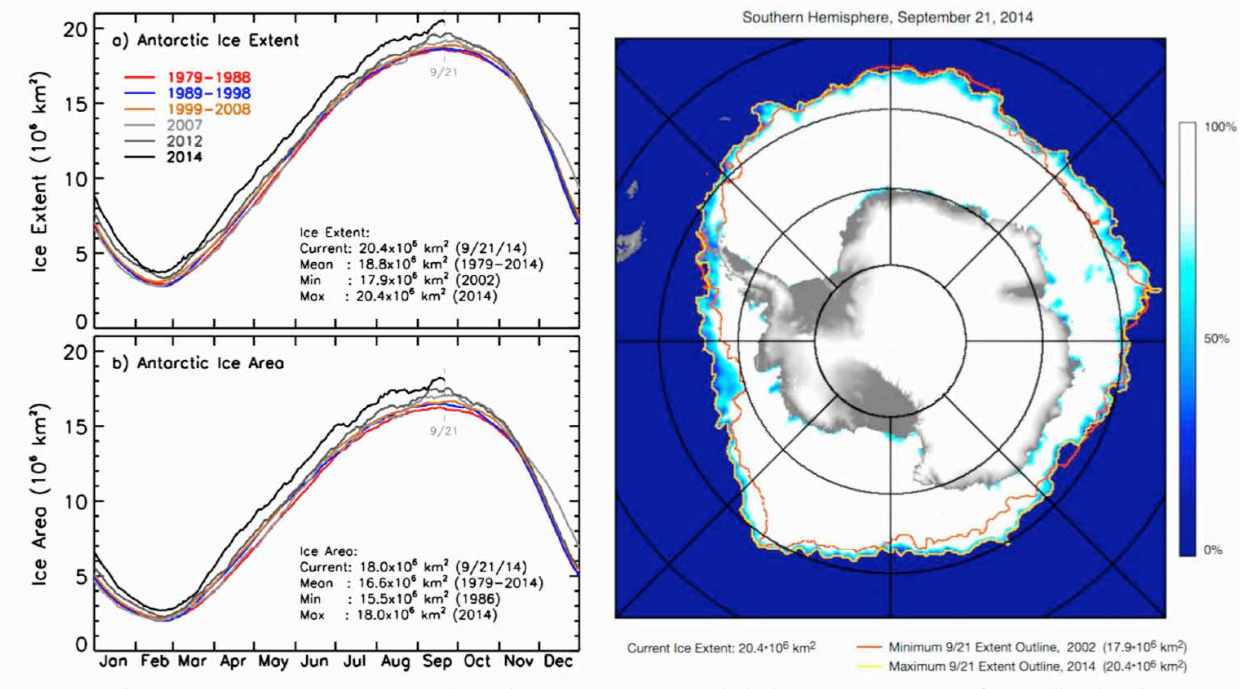


**Figure 2.** The current Antarctic sea ice extent [20.4 x 106 km² (~7.9 x 106 mi²)] is the highest since measurements from satellites have been taken. The extent of the September 21, 2014 sea ice is approximately 14% more than in 2002, when the Antarctic sea ice was at the satellite-era minimum for the date of September 21.

**Conclusion**

The AMSR Science Team meeting was successful in providing updates to everyone present on the status of the AMSR-E final algorithm development, processing, and plans for product distribution. The U.S. AMSR2 Science Team had a good discussion on a first step toward a more cohesive plan for its algorithm development e.g., having a homogeneous ancillary file. Most of the U.S. AMSR2 Science Team will be present at the JAXA GCOM-W1/AMSR2 PI Workshop in January 2015. No specific date was established for the next AMSR Science Team meeting in the US.

**Useful links**:

NASA AMSR-E website: *wwwghcc.msfc.nasa.gov/AMSR*

JAXA website: *global.jaxa.jp/projects/sat/gcom_w/index.html*

*suzaku.eorc.jaxa.jp/GCOM_W* ■

## Editorial

*continued from page 3*

many years of hard work that has made these accomplishments possible.

NASA is once again planning to have a large presence at the Fall American Geophysical Union (AGU) Meeting being held December 15-19 in San Francisco, CA. Two EOS-related sessions are worth highlighting. On December 18 (during AGU) Terra will celebrate 15 years in orbit. A special session for Terra is scheduled for December 19 (*Terra: 15 Years as the Earth Observing System Flagship Observatory*). Likewise, two sessions on December 17 will focus on the tenth anniversary of Aura (*Observations from Aura: An Integrated Observatory of Atmospheric Composition*). *The Earth Observer* will have more details on the Terra anniversary, and on these sessions at AGU in our next issue. For more information on these two sessions, please visit *fallmeeting.agu.org/2014*.

NASA will also have its booth in the exhibit hall throughout the week. Representatives from several different programs and missions are scheduled to give Hyperwall and Keynote presentations covering a diverse range of research topics spanning all of NASA's Science Mission Directorate. There will also be other science presentations, demonstrations, printed material, and tutorials on various data tools and services. A daily agenda will be posted on the Earth Observing System Project Science Office website in early December—*eospso.nasa.gov*. If you plan on attending AGU this year, we hope to see you at the exhibit. For more information see the advertisement on page 28 of this issue.

Finally, on behalf of *The Earth Observer* staff, our sincere appreciation to those of you who provided content for the newsletter over the past year. Thanks to you and your continued support, our publication is now in its 25th year! Best wishes to you and yours in the coming year. ■

# LANCE User Working Group Meeting Summary

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The Land, Atmosphere Near real-time Capability for EOS (LANCE) User Working Group (UWG) held its fourth annual meeting at NASA's Goddard Space Flight Center (GSFC) and via WebEx, on September 23, 2014. LANCE is the near-real-time (NRT) component of the Earth Observing System Data and Information System (EOSDIS); it provides data and imagery from the Aqua, Terra, and Aura spacecraft to various end users—including the applications user community, scientists, and operational agencies. Summaries of the previous LANCE workshops can be found in previous issues of *The Earth Observer*[1] and at *earthdata.nasa.gov/data/nrt-data/user-community/user-working-group-uwg*.

The LANCE UWG is composed of a representative selection of LANCE users who help steer the development of the LANCE program. In addition to UWG members, others who attended the meeting represented NASA Headquarters (HQ), the Earth Science Data and Information System (ESDIS), the LANCE elements[2], and other data providers. The purpose of the meeting was to review the status of LANCE and the progress made on previous UWG recommendations, and to identify and discuss potential enhancements and upgrades to the LANCE system.

**Kevin Murphy** [GSFC, ESDIS] opened the meeting, welcoming the attendees and identifying the scope and objectives of the meeting. **Chris Justice** [University of Maryland, College Park—*LANCE UWG Chair*] reminded the group that the UWG's role is to provide community feedback and guidance to LANCE, and that this could be done verbally at the meeting or by e-mail. Justice commented that LANCE has a strong applied science component and is an important part of NASA's data systems. Justice stated that some EOS instruments are getting old and that with new missions coming online, such as the Suomi National Polar-orbiting Partnership (NPP) and Soil Moisture Active Passive (SMAP), there are opportunities to broaden the NRT capability to these instruments. He encouraged attendees to consider new NRT applications from new missions, as well as providing continuity for existing products. To date, LANCE products have had a strong science algorithm heritage and associated maturity and are supported by NASA Science Teams. As LANCE transitions to new instruments, Justice suggested that the group should evaluate this approach, recognizing that product quality control is important and that LANCE needs to find a way to ensure continued support for any product enhancements.

**Lawrence Friedl** [NASA HQ—*Director of the Applied Sciences Program (ASP)*] introduced **David Green** [NASA HQ] as the new ASP Disasters Program Manager; he will also be the new LANCE Program Scientist. Friedl commented on the importance of LANCE to the ASP, echoing the perspective of the Applied Sciences Advisory Committee (ASAC), which released a report in May 2014 commenting that a constant and overriding theme throughout the ASAC meetings was the growing importance of applications to NASA's core mission—a natural outcome of NASA's multidecade commitment to understanding Earth from space.

Looking forward, Friedl said preparations are underway for the second Earth Science Decadal Survey, the first having been published in 2007. He estimated the publication release would be scheduled for 2017, which would require community input by 2015. As part of the preparations for the decadal survey, an *ad hoc* committee will review the needs for continuity of NASA-sustained remote sensing observations of the Earth from space[3]. He suggested the UWG should review the findings of this committee and make the case for continued NRT access from new missions as appropriate.

Friedl emphasized the need for early input on mission design to enable NRT access. As NASA has recently signed an agreement to distribute some data from the European Commission and European Space Agency (ESA) partnership's Sentinel[4] series of satellites, Friedl also suggested that the UWG might consider what NRT products they would like to see from future Sentinel satellites, as NASA will be distributing some of these data.

Reflecting on these comments, the discussions within the UWG acknowledged that LANCE is on track to expand beyond EOS—and beyond land and atmosphere data—and that an assessment of NRT data needs and the associated instrument and data systems requirements need to be addressed early in mission planning. The composition of the UWG will need to

[1] The most recent LANCE UWG was summarized in the September-October 2013 issue [**Volume 25, Issue 5**, pp. 17-20].

[2] The LANCE elements provide expedited processing using special algorithms for near-real-time processing. More information is available at *earthdata.nasa.gov/about-eosdis/science-system-description/eosdis-components/lance*.

[3] To review the framework for analyzing these needs, visit *sites.nationalacademies.org/SSB/CurrentProjects/SSB_084713.htm*.

[4] To learn more about the Sentinel missions please see "An Overview of Europe's Expanding Earth-Observation Capabilities" in the July–August 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 4**, pp. 4-15].

be revisited, or augmented, to provide guidance for new NASA data systems coming online. **Jeanne Behnke** [GSFC, ESDIS] suggested that the UWG might revisit the definition of NRT. As new applications and datasets become available, the definition could be expanded based on user needs for data prior to science data availability, rather than just "three hours after acquisition," which is the current LANCE latency requirement.

**Diane Davies** [GSFC, ESDIS—*LANCE Operations Manager*] gave an overview of LANCE's status, actions, and accomplishments. She reported that LANCE is operating well within its three-hour latency requirement and that the number of users and the amount of NRT data and imagery downloaded continues to rise. Since October 2013 there has been a three-fold increase in the NRT product downloads from Global Imagery Browse Services (GIBS), a core EOSDIS component. In July 2014 LANCE started generating new Vegetation Index (VI) and Surface Reflectance (SR) products, following requests from the dust modeling and agricultural monitoring communities. The new Moderate Resolution Imaging Spectroradiometer (MODIS) products are a daily eight-day rolling VI product, which includes both Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), and an eight-day rolling SR product. She also stated that LANCE is continuing to prototype secure http (*https)* data distribution, and that the LANCE Core Requirements are being revised in the Configuration Management EOSDIS Tool (COMET). The intent is to make the core document more generic, with separate appendices to manage information specific to each element. This modular approach will enable new sensors to be added to LANCE more easily. Davies also reminded the group that in 2013 EOSDIS initiated an American Customer Satisfaction Index (ACSI) Survey to assess customer satisfaction with LANCE. She reported that overall, the satisfaction rate among LANCE users was high, with a baseline score of 78[5]. A second ACSI survey will be conducted in the fall of 2014.

**Kathryn Regner** [University of Alabama in Huntsville] reported that LANCE is working to provide NRT data from the Advanced Microwave Scanning Radiometer 2 (AMSR2) instrument onboard the Japan Aerospace Exploration Agency's (JAXA) Global Change Observation Mission – Water (GCOM-W1). Regner provided an update on progress, stating that Level 1R (resampled) data are ingested from JAXA and that the U.S. AMSR2 Science Team is providing preliminary algorithms. So far, two algorithms are ready for testing: a Snow Water Equivalent (SWE) algorithm and a GSFC Profiling (GPROF2010) retrieval code for NRT AMSR2 precipitation and nonraining parameters. The first NRT AMSR2 products likely will be made available in early 2015, subject to products being approved by the Science Team.

**Feng Ding** [GSFC] provided an update on Aqua's Atmospheric Infrared Sounder (AIRS) and Aura's Microwave Limb Sounder (MLS). Both instruments are stable, with the exception of a single event upset that caused a loss of AIRS data for about one week in March 2014. Ding highlighted a study that demonstrated the contribution of NRT AIRS data in successfully predicting Hurricane Sandy, via numerical models.

**Phil Durbin** [GSFC] said that Aura's Ozone Monitoring Instrument (OMI) experienced a row anomaly around August 13, 2014, effectively blocking another 6 (out of 60) pixels in the part of the orbit greater than 50° N latitude. Unfortunately, this means that OMI cannot be used to monitor volcanic eruptions such as that from the Bardabunga volcano currently active in Iceland. An improved product that measures sulfur dioxide ($SO_2$) loads in the planetary boundary layer (PBL) should be available by mid-October 2014.

**Ed Masuoka** [GSFC] provided an update on MODIS Collection 6 (C6) reprocessing. Testing and reprocessing of atmosphere products are complete for Aqua, and almost complete for Terra. For land products, C6 Product Generation Executables (PGEs) are currently being prepared for NRT delivery, and expected to be operational within six months after the start of reprocessing at the MODIS Adaptive Processing System (MODAPS). Unless advised otherwise by the Science Team, all C6 PGEs will be run in parallel with Collection 5 (C5) version for one year to allow applications users time to make the transition to the new collection. Additional resources are being added to meet the latency requirement and the needed redundancy. Masuoka said that overall, MODIS NRT products are being generated within two hours of data acquisition for most Level 2 (L2) products, but latency varies for Level 3 (L3) products, ranging from 12-18 hours.

**Crystal Schaaf** [University of Massachusetts, Boston] and **Zhuosen Wang** [GFSC] provided an update on the rolling NRT Bidirectional Reflectance Distribution Function (BRDF) product that was requested at the May 2013 LANCE UWG to support worldwide air quality and atmospheric modeling communities. The NRT BRDF/Nadir BRDF-Adjusted Reflectance (NBAR)/Albedo algorithm is derived from the current (i.e., V006) MODIS algorithm (*MCD43*) and will be made available after the MODIS C6 NRT forward processing begins. There will be small differences between the NRT and the standard product due to the temporal weights applied to the algorithm. The NRT version emphasizes the last most recent day of the eight-day

[5] This score is on par with other information providers that have taken similar surveys, and is 10 points above the Federal Government average.

period, whereas the standard product will emphasize the middle of the day.

**Louis Giglio** [University of Maryland] presented a request to include per-pixel geolocation coordinates in the NRT Thermal Anomalies and Fire Algorithm (*MOD14*), as this would be useful for a range of NRT application users. The C6 MODIS fire code can optionally append geolocation layers (e.g., latitude and longitude) to swath products via a command-line switch. File sizes would be larger; however, as the NRT archive is a rolling archive, this would not have any significant impacts on production or hardware. The UWG approved this request.

**Lalit Wanchoo** [GSFC, ESDIS] presented an overview of the EOSDIS Digital Object Identifiers (DOIs) process[6], followed by a discussion in which the UWG was asked to consider whether they would recommend that DOIs be adopted for NRT data. DOIs are generally assigned to data products that are to be archived for a long time to ensure that data users can retrieve the data using DOIs cited in literature. Short-lived data products do not usually get DOIs, as the exact data product will not be available until after the data have been deleted. However, the UWG agreed that DOIs promote discoverability, accessibility, and reproducibility, and would help users distinguish between NRT and Standard Science Quality datasets. The UWG agreed there is no intent to archive NRT data. The UWG recommended DOIs be assigned to NRT datasets.

**Kevin Murphy** highlighted a number of updates from EOSDIS that are relevant to LANCE, as LANCE leverages a number of existing EOSDIS components, including the Earthdata website (*earthdata.nasa.gov*), the User Support Tool, and the User Registration System (URS).

**Andrew Molthan** [NASA's Marshall Space Flight Center] commented that finding data using LANCE is very easy and user-friendly; however, finding tools to process the data is more complicated. **Kevin Murphy** added that the Earthdata Code Collaborative (ECC) should make this easier—but there are some legal issues that have to be considered for tools not developed by NASA. He added that the provenance of science products is recorded through the algorithm theoretical basis documents (ATBDs), and that a similar approach should be sought to capture provenance for tools and nonscience products such as true-color images.

**Pamela Rinsland** [NASA's Langley Research Center, Atmospheric Science Data Center] presented an update on progress to make NRT Multi-angle Imaging SpectroRadiometer (MISR) data available. MISR NRT L2 winds products are available as HDF and BUFR files through OPeNDAP[7], within 2 hours and 20 minutes of satellite overpass time. Steps are underway to make the data available through LANCE.

**Dan Slayback** [GSFC] provided an update on how LANCE NRT data are being used for global flood mapping. The product is proving to be very useful to a wide range of organizations, but some improvements still need to be implemented before the product is considered to be robust enough for transition to an operational partner. These include a seasonal water layer to better identify floods, and better identification of terrain and shadow as they can be misclassified as flooded land. More information can be found on GSFC's Office of Applied Science (OAS) website at *oas.gsfc.nasa.gov/floodmap*.

**Andrew Molthan** reported that the Short-term Prediction Research and Transition Center (SPoRT) makes extensive use of LANCE products for weather, climate, and disaster applications—see *LANCE Data Being Used by NASA's SPoRT Center to Identify Hail or Tornado Damage* on page 40[8]. Molthan commented that SPoRT highly values the streamlined Applications Programming Interfaces (APIs) that allow for global search and acquisition of MODIS products. Futhermore, SPoRT would like to see these capabilities extended to Suomi NPP datasets and other NASA missions such as the Global Precipitation Measurement (GPM) mission. He said SPoRT applications that make use of data from Suomi NPP and GPM continue to grow, and there are plans to use data from the SMAP missions. LANCE-like data access would therefore be beneficial. SPoRT is highly interested in developing closer, collaborative partnerships to test and evaluate new LANCE capabilities for Suomi NPP, GPM, and other instruments. Reflecting on the presentation, the UWG considered the challenges of managing NRT products with varying levels of maturity, developed without NASA Science Team heritage; this is something LANCE has not dealt with in the past, but may need to consider moving forward.

**Alfreda Hall** [GSFC—*ESDIS Science Data Segment Manager and Suomi NPP Manager*] gave an update on Suomi NPP. Hall stated that it is too early to know which NASA NRT products will be produced from Suomi NPP data; it is anticipated more will be known in mid-November 2014. It was estimated that global Suomi NPP products would not be available before late

[6] To learn more, please see "Digital Object Identifiers for NASA's Earth Observing System" in the September–October 2012 issue of *The Earth Observer* [**Volume 24**, **Issue 5**, pp. 10-15].

[7] HDF stands for Hierarchical Data Format and BUFR stands for Binary Universal Form for the Representation; both are common file types for Earth science data. OPeNDAP stands for the Open-source Project for a Network Data Access Protocol, and is a well known data transport architecture and protocol widely used by Earth scientists.

[8] To learn more about SPoRT, please see "Transitioning NASA Earth-observing Satellite Data to the Operational Weather Community" in the May–June 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 3**, pp. 4-11].

2015, but that the Direct Readout Laboratory (DRL) would provide an interim source for nonglobal products. It was agreed that the UWG should consider ways to fast-track products to LANCE when they are ready.

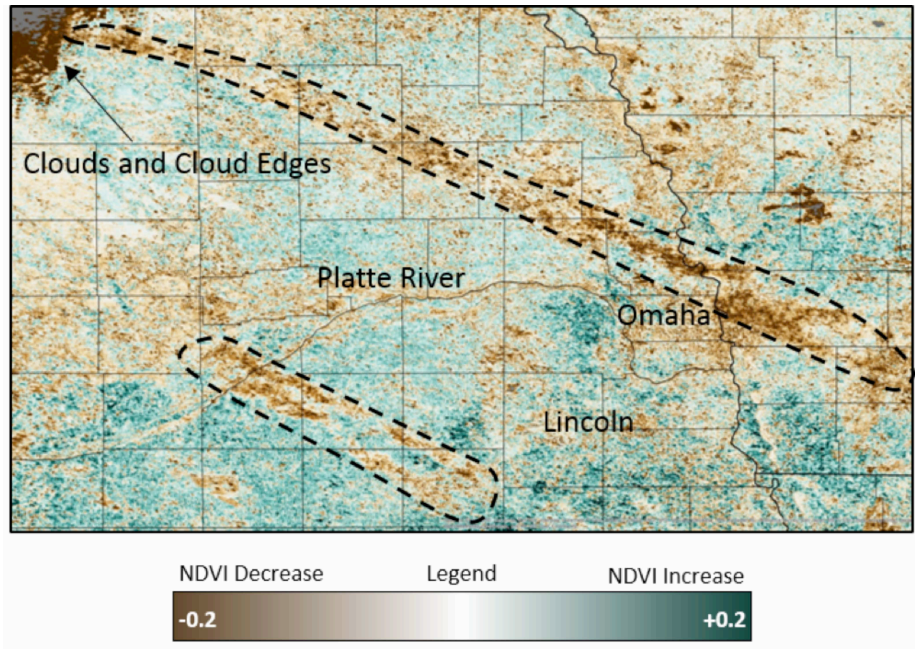
**Kevin Murphy** informed the group that NASA ESDIS would become a distribution hub for data from the Synthetic Aperture Radar onboard ESA's Sentinel 1. NASA will develop a Sentinel Data Gateway, which will pull Level 1 data from the Copernicus Data Hub. Sentinel 1 data will not be distributed in NRT.

**Chris Justice** closed the meeting by saying that overall, LANCE is doing well and has good visibility. LANCE seems to be coming to a turning point where it will move beyond EOS data; in the short term, this will include data from Suomi NPP and SMAP. Justice suggested the UWG look at possible NRT applications from Suomi NPP and suggested we invite a science team lead for SMAP to the next LANCE UWG meeting to highlight SMAP NRT applications. Justice ended by summarizing the UWG recommendations:

- The UWG should provide input in to the upcoming Decadal Survey on Earth Science;
- add per-pixel geolocation coordinates to the NRT Thermal Anomalies and Fire product (*MOD14*);
- create DOIs for LANCE data;
- meet the LANCE core requirements to enable NRT MISR to be distributed through LANCE; and
- explore which planned NASA Suomi NPP Science Products could have a NRT equivalent and could be made available through LANCE. ■

## LANCE Data Being Used by NASA's SPoRT Center to Identify Hail or Tornado Damage

NASA's SPoRT is a long-term user of LANCE data to provide NRT information for weather and disaster applications where direct broadcast MODIS data are unavailable. Recently, SPoRT started using NRT MODIS observations to identify short-term NDVI change following severe weather to show hail or tornado damage scars when corroborated with other storm information. This information is provided to the National Weather Service Damage Assessment Toolkit for use in the field.




Using data from LANCE, SPoRT created this image showing hail damage scars across Nebraska. The image was created using NRT Surface Reflectance data from Terra that were used to create a 14-day maximum NDVI composite ending in June 10, 2014. The image shows the difference between NDVI observed on June 11, 2014 and the previous 14 days ending June 10. Contiguous areas of NDVI decrease (darkest browns) are oriented from northwest to southeast along the paths of severe thunderstorms from June 3 that produced widespread wind damage and damage from hail up to 4.25 in (~10.8 cm) in diameter in parts of eastern Nebraska. Portions of the hail swaths are apparent in the days immediately following the storms; however, results from June 11 are shown here as the area was generally cloud-free.

# NASA's ECOSTRESS Will Monitor Plant Health

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

A new space-based instrument to study how effectively plants use water is being developed at NASA/Jet Propulsion Laboratory and will fly onboard the International Space Station. The instrument, called the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), will monitor one of the most basic processes in living plants: the loss of water through the tiny pores in leaves.

When people lose water through their pores, the process is called sweating. The related process in plants is known as *transpiration*. Because water that evaporates from soil around plants also affects the amount of water that plants can use, ECOSTRESS will measure combined evaporation and transpiration, known as *evapotranspiration*.

"When a person sweats during a workout, it helps cool their body, and if they get enough water they can keep exercising," said **Simon Hook** [JPL—*ECOSTRESS Principal Investigator*]. "If they do not get enough water, they show signs of overheating and stress and eventually collapse. Similarly, if plants do not get enough water, they show signs of stress. By measuring evapotranspiration, we get an early indicator of that stress, and we can do something about it before the plants collapse."

ECOSTRESS's science instrument is a high-resolution thermal infrared radiometer, which works like a giant thermometer from space to measure the temperature of plants and the amount of heat radiating from Earth's surface. "If we find a plant is too hot, that's because it's not getting enough water to cool itself down," said **Josh Fisher** [JPL—*ECOSTRESS Science Lead*]. "We see in our own gardens that one type of plant needs more water to grow than the next plant, but we have not been able to 'see' this on a global scale," Fisher noted. "That has huge implications for our understanding of global water and carbon cycling, and which plants are going to live or die in a future world of greater droughts."

Existing satellite instruments that monitor evapotranspiration offer either high spatial resolution but low time frequency (a couple of measurements a month), or high time frequency and coarse spatial resolution—500 $m^2$ (1600 $ft^2$). Scientists, farmers, and water managers need both high resolution and high frequency. ECOSTRESS will provide a four-day repeat cycle and a spatial resolution of 38 m (125 ft) by 57 m (185 ft), which is high enough to see most farms and small differences within ecosystems.

"We are keeping an eye on how ECOSTRESS can be applied not only to science but society at large," said **Andy French** [U.S. Department of Agriculture] who is a scientist and member of the ECOSTRESS team. "It could be very useful for water managers and farmers." By combining the instrument's measurements with other ecosystem data, scientists will be able to calculate how efficiently plants use water to process carbon dioxide and identify plants likely to be more resilient during droughts. The mission will target regions where models disagree about water use efficiency, and ECOSTRESS data will be used to improve those models.

The International Space Station provides a particularly beneficial vantage point not regularly available with traditional "free-flying" (i.e., sun-synchronous, polar-orbiting) satellites, which fly over the same spot on Earth at the same time on each pass. The station's orbit shifts so that it flies over any given spot on Earth at different times. By looking at ECOSTRESS imagery of a certain location over the course of days to weeks, scientists will be able to see how evapotranspiration varies in that location throughout the day. This is important, because plants that get enough water in the cool of the morning might shut down in afternoon heat, just as a person stops sweating under extreme heat stress. Up until now, scientists have not known at the global scale in which ecosystems plants shut down in the afternoon and in which ecosystems plants do not, and what environmental conditions influence this basic characteristic.

Scheduled for completion in 2017, and launch between 2017 and 2019, ECOSTRESS is one of two instruments selected in July for NASA's Earth Venture-Instrument series of missions. These missions are part of the Earth System Science Pathfinder program, managed by NASA's Langley Research Center, for NASA's Science Mission Directorate. The ECOSTRESS team includes researchers from the U.S. Department of Agriculture; Princeton University, Princeton, New Jersey; and the University of Idaho, Moscow, Idaho. ■

in the news

# NASA Begins Sixth Year of Airborne Antarctic Ice Change Study

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

NASA is carrying out its sixth consecutive year of *Operation IceBridge* research flights over Antarctica to study changes in the continent's ice sheet, glaciers, and sea ice. This year's airborne campaign, which began its first flight October 16, will revisit a section of the Antarctic ice sheet that recently was found to be in irreversible decline.

For the next several weeks, researchers will fly onboard NASA's DC-8 research aircraft out of Punta Arenas, Chile. This year also marks the return to western Antarctica following 2013's campaign based at the National Science Foundation's McMurdo Station. "We are curious to see how much these glaciers have changed in two years," said glaciologist **Eric Rignot**, [University of California, Irvine, NASA/Jet Propulsion Laboratory—*IceBridge Science Team Co-Lead*].

NASA's DC-8 research aircraft will be flying scientists and instruments over Antarctica to study changes in the continent's ice sheet, glaciers, and sea ice. **Image credit:** NASA

IceBridge will use a suite of instruments that includes a laser altimeter, radar instruments, cameras, and a gravimeter, which is an instrument that detects small changes in gravity. These small changes reveal how much mass these glaciers have lost. Repeated annual measurements of key glaciers maintains a long-term record of change in the Antarctic that goes back to NASA's Ice, Cloud and land Elevation Satellite (ICESat), which stopped collecting data in 2009.

IceBridge researchers plan to measure previously unsurveyed regions of Antarctica. One example is a plan to look at the upper portions of Smith Glacier in West Antarctica, which is thinning faster than any other glaciers in the region. The mission also plans to collect data in portions of the Antarctic Peninsula, such as the Larsen C, George VI, and Wilkins ice shelves and the glaciers that drain into them. The Antarctic Peninsula has been warming faster than the rest of the continent.

"The Antarctic Peninsula is changing fairly rapidly and we need to be there to capture that change," said **Michael Studinger** [NASA's Goddard Space Flight Center (GSFC)—*IceBridge Project Scientist*].

The mission also will collect data on Antarctic sea ice, which recently reached a record high coverage[1]. This contrasts with declining sea ice in the Arctic and is due do a variety of factors, such as changing wind patterns. Antarctic sea ice coverage is slightly above average and the growth varies from one part of Antarctica to another. For example, ice cover in the Bellingshausen Sea has been decreasing while ice in the nearby Ross Sea is growing. "There are very strong regional variations on how sea ice is changing," said **Nathan Kurtz** [GSFC]. These regional trends together yield a small increase, so studying each region will help scientists get a better grasp on the processes affecting sea ice there.

In addition to extending ICESat's data record over land and sea ice, IceBridge will also help set the stage for ICESat-2 (scheduled for launch in 2017) by measuring ice the satellite will fly over. One of IceBridge's highest priority surveys is a circular flight the DC-8 will fly around the South Pole at 88° S latitude. This latitude line is where all of ICESat-2's orbits will converge in the Southern Hemisphere. Measuring ice elevation at these locations will help researchers build a time series of data that spans more than a decade and provide a way to help verify ICESat-2's data.

IceBridge's Antarctic field campaign will run through late November. The IceBridge project science office is based at GSFC. The DC-8 research aircraft is based at NASA's Armstrong Flight Research Center. For more information about Operation IceBridge, visit *www.nasa.gov/icebridge*. ■

[1] The value is the highest ever recorded during the satellite era, which dates back to 1979.

# 2014 Antarctic Ozone Hole Holds Steady

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

The Antarctic ozone hole reached its annual peak size on September 11, 2014, according to scientists from NASA and the National Oceanic and Atmospheric Administration (NOAA)—see **Figure 1**. The size of this year's hole was 24.1 million km$^2$ (9.3 million mi$^2$)—an area roughly the size of North America.

The single-day maximum area was similar to that of 2013, which reached 24.0 million square km$^2$ (9.3 million mi$^2$). The largest single-day ozone hole ever recorded by satellite was 29.9 million km$^2$ (11.5 million mi$^2$) on September 9, 2000. Overall, the 2014 ozone hole is smaller than the large holes of the period from 1998 to 2006, and is comparable to those that occurred in 2010, 2012, and 2013.

With the increased atmospheric chlorine levels present since the 1980s, the Antarctic ozone hole forms and expands during the Southern Hemisphere spring (August and September). The ozone layer helps shield life on Earth from potentially harmful ultraviolet radiation that can cause skin cancer and damage plants.

The Montreal Protocol agreement enacted in 1987, and modified several times since, regulated ozone-depleting substances, such as chlorine-containing chlorofluorocarbons and bromine-containing halons. The 2014 level of these substances over Antarctica has declined about 9% below the record maximum in 2000.

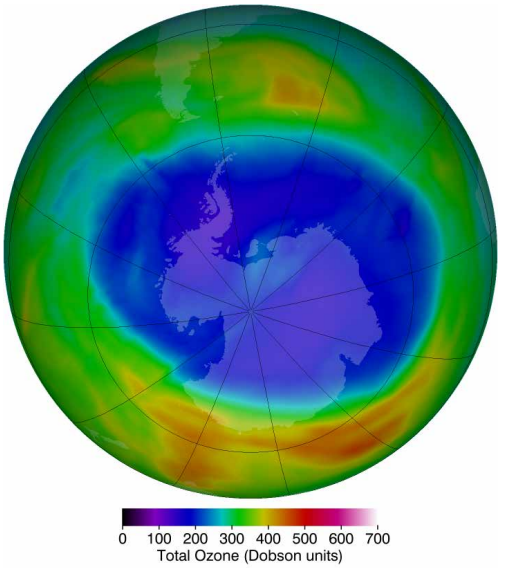


**Figure 1.** This image shows ozone concentrations above Antarctica on September 11, 2014. **Image credit:** NASA

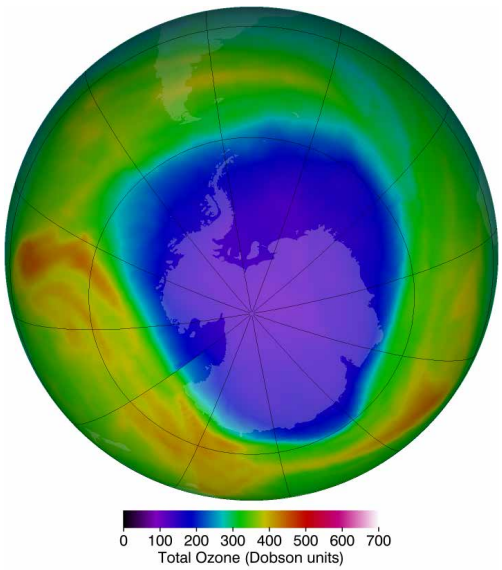


**Figure 2.** This image shows ozone concentrations above Antarctica on September 30, 2014. **Image credit:** NASA

"Year-to-year weather variability significantly impacts [ozone in Antarctica] because warmer stratospheric temperatures can reduce ozone depletion," said **Paul Newman** [NASA's Goddard Space Flight Center—*Chief Scientist for Atmospheres*]. "The ozone hole area is smaller than what we saw in the late-1990s and early 2000s, and we know that chlorine levels are decreasing. However, we are still uncertain about whether a long-term Antarctic stratospheric temperature warming might be reducing this ozone depletion."

Scientists are working to determine if the ozone hole trend over the last decade is a result of temperature increases or chorine declines—or both. An increase of stratospheric temperature over Antarctica would decrease the ozone hole's area. Satellite and ground-based measurements show that chlorine levels are declining, but stratospheric temperature analyses in that region are less reliable for determining long-term trends.

Scientists also found that the minimum thickness of the ozone layer this year was recorded at 114 Dobson Units (DU) on September 30—see **Figure 2**—compared to 250-350 DU during the 1960s. Over the last 50 years, satellite and ground-based records over Antarctica show ozone column amounts ranging from 100 to 400 DU, which translates to about 1 mm (1/25 in) to 5 mm (1/6 in) of ozone in a layer if all of the ozone were brought down to the surface.

continued on page 46

# NASA Earth Science in the News

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***Scientists Say Ozone Layer is Recovering, Credit Phase-Out of Aerosol Chemicals since the 1980s,** September 10; *Associated Press*. Earth's protective ozone layer is beginning to recover from its previously reduced levels, largely because of the phase-out since the 1980s of certain chemicals used in refrigerants and aerosol cans, a U.N. scientific panel reported. Scientists said the development demonstrates that when the world's peoples come together, we can counteract a brewing ecological crisis. For the first time in 35 years, scientists were able to confirm a statistically significant and sustained increase in stratospheric ozone, which shields the planet from solar radiation that causes skin cancer, crop damage, and other problems. From 2000 to 2013, ozone levels climbed 4% in the key mid-northern latitudes at about 48 km (30 mi) above Earth's surface, said scientist **Paul Newman** [NASA's Goddard Space Flight Center (GSFC)].

****NASA Projects Tracking Changes in Alaska's Glaciers and Arctic Atmosphere,** September 17; *Alaska Dispatch News*. To study the rapidly warming climate in Alaska and other parts of the Far North, NASA has launched three Alaska-based airborne campaigns to better understand how such warming is changing the size and behavior of glaciers, the release of carbon gases from thawing permafrost, and the interplay between sea ice, clouds, and weather in and above the Arctic Ocean. The three projects are Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE), Operation IceBridge-Alaska, and Arctic Radiation IceBridge Sea and Ice Experiment (ARISE). ARISE, which in 2014 made research flights over Arctic sea ice, was a new campaign. "We have some expectation that less sea ice cover over the Arctic Ocean could lead to more clouds," said **Bill Smith** [NASA's Langley Research Center—*ARISE Principal Investigator*]. Assuming that is true, there are still unanswered questions, such as whether increased cloud cover will have a cooling effect by reflecting solar heat, or a warming effect by trapping heat from the surface below. "The data we're collecting from the C-130 are intended to help sort this out," Smith said.

**Deep Ocean Hasn't Warmed Measurably in a Decade, Says NASA,** October 6; *The Weather Channel*. Deep below the ocean surface, there's a place global warming hasn't yet reached. According to a study published on October 5, 2014, in *Nature Climate Change*, scientists at NASA/Jet Propulsion Laboratory (JPL) have found that over the last decade the deepest part of the world's ocean has not warmed measurably. The scientists analyzed ocean temperatures from between 2005 and 2013 and found that below a depth of approximately 2 km (~1.2 mi)—roughly halfway to the bottom at this location—the global ocean has not warmed nearly as quickly as the top half. The scientists collected the temperature data using both satellite measurements and data from the Argo array (*www.argo.ucsd.edu*), a network of some 3500 floating probes scattered throughout the world that measure ocean temperatures and salinity. "The sea level is still rising," said study co-author **Josh Willis** [JPL] in a news release. "We're just trying to understand the nitty-gritty details."

***Antarctic Sea Ice Level Breaks Record, NASA Says,** October 9; *CBSNews.com*. Sea ice surrounding Antarctica is at an all-time high, even as global temperature averages continue to climb. NASA reports that ice formation in the continent's southern oceans peaked this year, breaking ice-measuring satellite records dating back to the late 1970s. For the first time since 1979, on September 19, 2014, Antarctic sea ice extent exceeded ~20 million km$^2$ (~7.7 million mi$^2$) whereas the average maximum extent between 1981 and 2010 was ~19 million km$^2$ (~7.3 million mi$^2$). Despite this trend, sea ice as a whole is decreasing on a global scale. Researchers say that, just like global warming, trends have different outcomes in different parts of the world; not every location with sea ice will experience ice loss or gain. "When we think about global warming we would expect intuitively that ice should also be declining in the Antarctic region as in the Arctic," explained senior research scientist **Josefino Comiso** [GSFC]. "But station and satellite data currently show that the trends in surface temperatures are most positive in the Arctic, while in the Antarctic region the trends are a mixture of positive and negative trends," he said, adding that cooling and declining sea surface temperatures could also contribute to a "more rapid advance at the ice edge."

**America's Tiny Four Corners Region is an Outsized Methane Hotspot,** October 10; *TIME.com*. One small spot in the U.S. Southwest is surprisingly the producer of the largest concentration of methane ($CH_4$) gas seen across the nation. Levels of $CH_4$ over the Four Corners region are more than triple the standard ground-based estimate of the greenhouse gas, as reported in a joint study of satellite data by scientists at JPL and the University of Michigan. $CH_4$ is a heat-trapping gas whose increasing quantities in the atmosphere have fueled concerns about global climate change. The methane "hotspot," seen on the map as a small splotch—see **Figure**—measures approximately 6475 km$^2$ (2500 mi$^2$)

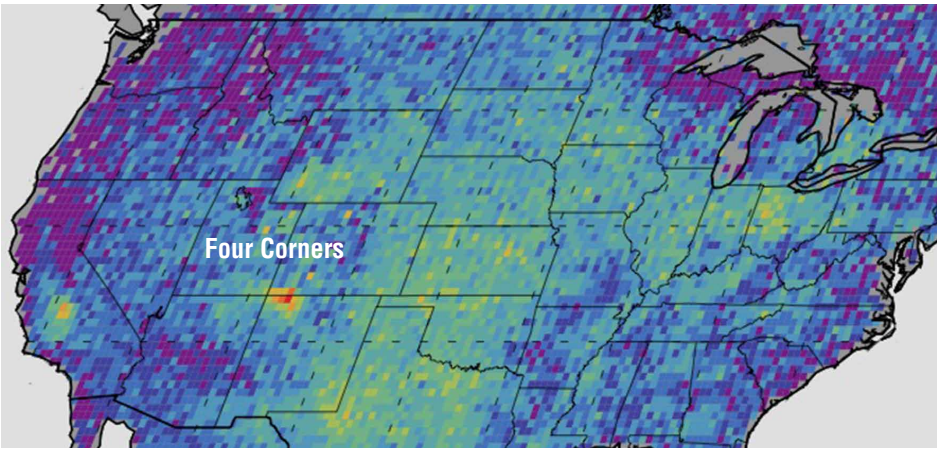


**Figure.** The Four Corners area is the major U.S. hotspot for methane emissions. This map shows how emissions in the region varied from national average background concentrations from 2003 through 2009. Purple and blue represent lower-than-average emissions, while orange shades represent higher concentrations. **Image credit:** NASA/JPL-Caltech/ University of Michigan

at the junction of Arizona, New Mexico, Colorado, and Utah. For scale, the state of Arizona is about 292,668 km$^2$ (113,000 mi$^2$). But the area generated an annual 0.59 million metric tons of methane between 2003 and 2009—about as much $CH_4$ as the entire coal, oil, and gas industries of the U.K. give off each year.

**NASA Inaugurates New Earth Observation Era with Space Station-Mounted RapidScat Instrument[1],** October 12; *UniverseToday.com*. NASA inaugurated a new era of research for the International Space Station (ISS) as an Earth-observation platform following the successful installation and activation of the ISS Rapid Scatterometer (ISS-RapidScat) science instrument, mounted on Europe's Columbus module. This is NASA's first research payload aimed at conducting near-global Earth science from the station's exterior and will be augmented with others in coming years. ISS-RapidScat is designed to monitor ocean winds for climate research, weather predictions, and hurricane monitoring. The experimental instrument is already collecting its first science data following its recent power-on and activation at the station. "Most satellite missions require weeks or even months to produce data of the quality that we seem to be getting from the first few days of ISS-RapidScat," said **Ernesto Rodriguez** [JPL—*ISS-RapidScat Project Scientist*]. "We have been very lucky that within the first days of operations we have already been able to observe a developing tropical cyclone. The quality of these data reflects the level of testing and preparation that the team has put in prior to launch. It also reflects the quality of the spare Quick Scatterometer (QuikSCAT) hardware, from which ISS-RapidScat was partially assembled."

**1934's Dust Bowl Drought Was the Worst in a Thousand Years for U.S.: NASA,** October 15; *NBCNews.com*. The drought of 1934 wasn't just bad, it was the worst. That's the finding of a reconstruction of North American drought history over the past 1000 years, done by scientists from NASA and Columbia University's Lamont-Doherty Earth Observatory. Their study, published in the October 17 issue of *Geophysical Research Letters*, concludes the drought of 1934, during the Dust Bowl years in the North American Plains, was 30% more severe than the next worst, which occurred in 1580, NASA scientists said. The scientists used tree ring records from 1000 to 2005 along with modern observations. They found that the 1934 drought extended across over 71% of western North America, compared with almost 60% during the 2012 drought. "It was the worst by a large margin," said lead author of the study **Ben Cook** [NASA's Goddard Institute for Space Studies—*Climate Scientist*]. The scientists found two main reasons: a winter high-pressure system over the West Coast that blocked precipitation and spring dust storms that suppressed rainfall.

**GRACE Spacecraft Changed the Way Groundwater was Measured,** November 16; *CBS' 60 Minutes*—**Leslie Stahl** hosted a segment on California's groundwater issues. The segment described the difficulty in sampling groundwater levels until NASA's Gravity Recovery and Climate Experiment (GRACE) spacecraft was launched. **Mike Watkins** [JPL—*GRACE Project Scientist*] described how GRACE "can tell whether an area has gained water weight or lost it." **Jay Famiglietti** [University of California, Irvine] said that he thought the method was "complete nonsense" until he started examining the data, which changed his position. The broadcast noted that Famiglietti was so worried by what he saw in the data that he is working "to alert governments and academics to the problem."

*See news story in this issue.

**See Blog Log in this issue.

*Interested in getting your research out to the general public, educators, and the scientific community? Please contact **Patrick Lynch** on NASA's Earth Science News Team at **patrick.lynch@nasa.gov** and let him know of upcoming journal articles, new satellite images, or conference presentations that you think would be of interest to the readership of **The Earth Observer**.* ■

[1]To learn more about ISS-RapidScat read "ISS-RapidScat: Measuring Ocean Winds from the International Space Station" in the September-October issue of *The Earth Observer* [**Issue 25, Volume 5,** pp. 4-9].

# NASA Science Mission Directorate – Science Education and Public Outreach Update

*Theresa Schwerin, Institute for Global Environmental Strategies, theresa_schwerin@strategies.org*
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**"Extreme Weather" Quiz from NASA's Know Your Earth Project is Now Live**

The new "Extreme Weather" quiz from NASA's *Know Your Earth* Project is now available online at *climate.nasa.gov/quizzes/extremeweather-quiz*. The Know Your Earth Project aligns with the larger NASA *Earth Right Now* Campaign through the creation of quizzes related to NASA's Earth science activities. To date, six quizzes have been released. The results of each of the quizzes can be shared on your social media pages.

To view the complete collection of quizzes visit *www.nasa.gov/content/know-your-earth-2014/#.VFubIr5UGA0*.

**NASA Climate Kids—Climate Change and Drought**

Drought is a serious problem—just ask the people of California. As the state approaches its fourth year of devastating drought, the importance of efficient farming continues to grow, with particular emphasis on monitoring soil moisture. In NASA Climate Kids' latest article, learn how a NASA mission will help farmers with this challenge, and about droughts and climate change in general.

Check it out online at *climatekids.nasa.gov/soil*.

**SciJinks: What is the Coriolis Effect?**

Every tropical cyclone (which includes hurricanes and typhoons) spins counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. This difference is because of an important physics principle called the *Coriolis Effect*. Such effects are at the same time important, weird, and confusing to many people.

Learn all about the Coriolis Effect by reading SciJinks' latest article at *scijinks.jpl.nasa.gov/coriolis*.

**GLOBE/NASA Satellite Partnerships—Don't Miss the Opportunity to Become Part of a NASA Mission with GLOBE**

Along with the ongoing CloudSat and Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) missions, in their 2014-2015 activities the GLOBE Program involves educators, students, and scientists in two new NASA satellite partnerships: the Global Precipitation Measurement (GPM) Core Observatory, launched on February 27, 2014, and the Soil Moisture Active Passive (SMAP) mission, scheduled for launch in January 2015.

The GLOBE Implementation Office (GIO) invites members of the NASA scientific community to get involved by becoming a member of the GLOBE International Scientist Network (GISN). Lend your expertise to students in activities related to satellite missions; Earth and atmospheric science research; and science, technology, engineering, and mathematics (STEM) education.

Learn more about ways to participate on the GISN webpage at *www.globe.gov/web/globe-international-scientist-network/overview.* For more information, contact *science@globe.gov*. ■

# 2014 Antarctic Ozone Hole Holds Steady

*continued from page 43*

The ozone data come from the Dutch-Finnish Ozone Monitoring Instrument onboard Aura and the Ozone Monitoring and Profiler Suite instrument onboard the NASA-NOAA Suomi National Polar-orbiting Partnership satellite. NOAA measurements at a South Pole station monitor the ozone layer above that location by means of Dobson spectrophotometer and regular ozone-sonde balloon launches that record the thickness of the ozone layer and its vertical distribution. Chlorine amounts are estimated using NOAA and NASA ground measurements and observations from the Microwave Limb Sounder onboard Aura.

NASA and NOAA are mandated under the Clean Air Act to monitor ozone-depleting gases and stratospheric depletion of ozone. Scientists from NASA and NOAA have been monitoring the ozone layer and the concentrations of ozone-depleting substances and their breakdown products from the ground and with a variety of instruments on satellites and balloons since the 1970s. These observations allow us to provide a continuous long-term record to track the long-term and year-to-year evolution of ozone amounts. ■

## EOS Science Calendar

**January 6–8, 2014**
ESIP Federation Meeting, Washington, DC.
*esipfed.org/meetings*

**February 3–5, 2015**
Landsat Science Team Meeting, Greenbelt, MD.

**April 20–24, 2015**
4th NASA Carbon Cycle and Ecosystems Joint Science Workshop, College Park, MD.
*cce.nasa.gov/cce/meetings.htm*

**April 22–23, 2015**
LCLUC Spring Science Team Meeting, College Park, MD.
*lcluc.umd.edu/meetings.php?mid=61*

**September 21-23, 2015**
GRACE Science Team Meeting, Austin, TX.
*www.csr.utexas.edu/grace/GSTM*

## Global Change Calendar

**December 15–19, 2014**
American Geophysical Union Fall Meeting, San Francisco, CA.
*meetings.agu.org*

**January 4–8, 2015**
American Meteorological Society Annual Meeting, Phoenix, AZ.
*annual.ametsoc.org/2015*

**January 14–16, 2015**
AMSR2 Workshop, Tokyo, Japan.

**January 27–29, 2015**
15th National Conference and Global Forum on Science, Policy and the Environment, Washington, DC.
*www.energyandclimatechange.org*

**February 12–15, 2015**
AAAS Annual Meeting, San Jose, CA.
*meetings.aaas.org*

**May 11–15, 2015**
36th International Symposium on Remote Sensing of Environment, Berlin, Germany.
*www.symposia.org*

**May 24–28, 2015**
Japan Geophysical Union Meeting, Chiba, Japan.
*www.jpgu.org/meeting_e*

**June 22–July 2, 2015**
26th International Union of Geodesy and Geophysics, Prague, Czech Republic.
*www.iugg2015prague.com*

**July 26–31, 2015**
IEEE International Geoscience and Remote Sensing Symposium, Milan, Italy.
*www.igarss2015.org*

**August 2–7, 2015**
12th Annual Asia Oceania Geosciences Society Meeting, Singapore, Japan.
*www.asiaoceania.org/aogs2015*

**August 16_-20, 2015**
250th American Chemical Society National Meeting, Boston, MA.
*www.acs.org/content/acs/en/meetings*

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*The Earth Observer* is published by the EOS Project Science Office, Code 610, NASA's Goddard Space Flight Center, Greenbelt, Maryland 20771, telephone (301) 614-5561, FAX (301) 614-6530, and is available in color at *eospso.nasa.gov/earth-observer-archive*. Black and white hard copies can be obtained by writing to the above address.

Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address. Newsletter content is due on the weekday closest to the 15th of the month preceding the publication—e.g., December 15 for the January–February issue; February 15 for March–April, and so on.

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NP-2014-1-118-GSFC